D07.2 V&V Report #2: Methodology definition, analyses results and certification

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Abstract	This deliverable is an intermediate report on the V&V activities undertaken in WP07. This document present research and application results. These deal with 1) the testing and analysis of the WP07 targets, 2) tools for the analysis of C and C++, 3) trust and security metrics and methodology improvements, and 4) certifiability of the XEN target.
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Table of Contents

1 Summary.......... 6
2 Introduction 7
2.1 Outline.......... 7
2.2 Targets analyses.......... 8
2.3 Structure of this report.......... 8
3 Development of security and trust metrics.......... 10
3.1 Overview.......... 10
3.2 Technical background.......... 10
3.3 Security Metrics.......... 13
3.4 Trust metrics.......... 25
3.5 Complexity.......... 28
3.6 Testing Methodology Improvements.......... 33
3.7 On-going work and future directions.......... 34
4 Dynamic analysis of targets.......... 35
4.1 Overview.......... 35
4.2 Technical background.......... 36
4.3 Testing the IFX TSS.......... 39
4.3.2.1 Test summary.......... 45
4.3.2.2 Black-box SOAP testing.......... 50
4.3.2.3 White-box testing.......... 53
4.4 Testing of XEN.......... 58
4.5 On-going work and future directions.......... 59
5 Static analysis of targets using AI.......... 60
5.1 Overview.......... 60
5.2 Enhancements and support of Frama-C.......... 61
5.3 Research on the static analysis of C++ code.......... 64
5.4 Static Analysis of XEN using Coverity.......... 72
5.5 Static Analysis of XEN using Frama-C.......... 80
5.6 On-going work and future directions.......... 87
6 Feasibility study: Xen and Common Criteria EAL5 evaluation.......... 89
6.1 Overview.......... 89
6.2 Availability of documentation.......... 90
6.3 Xen architecture and immediate implications.......... 90
6.4 Common Criteria components.......... 92
6.5 Security Target properties.......... 95
6.6 Conclusion, discussion.......... 97
6.7 Abbreviations.......... 99
7 References.......... 100

List of figures

Figure 1: Test process overview... 37
Figure 2: Code snippet before instrumentation.. 41
Figure 3: Modified code.. 41
Figure 4: Hooking cycle.. 42
Figure 5: SOAP transport level hooking.. 44
Figure 6: Processing a C++ file in Frama-C.. 67
Figure 7: Correspondence between the implementation and the ghost model............ 72

Index of Tables

Table 1: Terminology... 14
Table 2: Calculating OPSEC.. 15
Table 3: Calculating Controls.. 17
Table 4: Calculating Security Limitations.. 22
Table 5: Calculating Actual Security... 24
Table 6: Statistics on test categories.. 50
Table 7: SOAP message testing summary... 51
Table 8: White-box testing summary.. 54
Table 9: Functions returning pointers... 75
Table 10: Functions returning numerical values.. 75
Table 11: Categories of potential bugs.. 82
Table 12: Bugs per categories.. 87
Table 13: Bugs statistics.. 87
Table 14: Differences between EAL4 and EAL5... 92

1 Summary

OpenTC sets out to develop trusted and secure computing systems based on Trusted Computing hardware and Open Source Software. This deliverable is the main output of WP07 for the second yearly period, i.e. from November 2006 to October 2007. It describes the main results of that period as well as work in progress of all partners of WP07, i.e. of BME, CEA, ISECOM, SUSE and TUS. These results stem from various research directions, and are directly related to the OS developments and their building blocks. The main results are the development of testing and verification tools, their application to OS components and the definition of an Open Source Security testing Methodology.

In this report we only present the research and development results for that period, but do not address any project management issues, for which the reader is invited to open the activities report.

2 Introduction

2.1 Outline

The initial and still actual main objectives of this WP is to evaluate the reliability and security of the OS code issued by WP04 (that is a combination of a trusted XEN/L4 virtualisation layer and the Linux kernel) by means of extensive testing and static analysis, guided by an proper methodology. The aim is to quantify the quality and safety of this OS code, provide feedback to the developers of this code, and analyze the possibility to certify (parts of) it at levels EAL5+.

Indeed, operating systems form a particular class of applications in terms of development process and code that need particular adaptations in terms of methodology, methods and tools. Starting from state of the art V&V techniques, we studied how to analyze and test the OS code with a maximum of precision.

WP07 has done significant progress toward the objectives set initially. All support tasks are focussed on the main objectives above and decomposed it into simpler objectives. This has been done in several ways.

BME has improved the testing methodology by the addition of trust and security metrics. Research has been done on how these metrics are applied to applications, especially the WP07 targets. Also the complexity of the targets became a subject of investigations, between several partners, aiming at understanding why the hypervisors are quite difficult targets in terms of V&V.

BME has tested intensively the TSS, by running 135 000 test cases, that revealed **8 weaknesses and 1 remotely exploitable buffer overflow**. All of these have been corrected and non-regression tests have confirmed this. Plans for testing the XEN core hypercalls are made.

WP07 has analysed statically the XEN core, especially focussing on five hypercalls designated by CUCL as the most critical. The Coverity Prevent tool has been used by TUS and has produced over **300 potential bugs on these hypercalls and a total of 1900 warnings on XEN versions 3.0.3, 3.0.4 and 3.1**. The Frama-C prototype has also been applied by CEA to the same hypercalls of **XEN 3.0.3 and has produced 170 potential errors amongst which 17 true errors.** These lists of potential bugs are being filtered and pruned, to keep only real errors.

WP07 has also developed several tools: the Frama-C tool has been improved by CEA to improve the precision and efficiency of the analyses and correct bugs and weaknesses discovered along its usage. Another tool is being developed by TUS to analyse the severity of potential bugs and perform slicings of the code to find out what portions of code are influenced by given errors or variables.

ISECOM has developed the security testing methodology for security testing within the OpenTC security testing activities as well as defined types of test activities and report tables. After the definitions have been set during the first project year, WP07 has studied how to quantify Trust and Security in a measurable manner. WP07 has also designed and implemented a security complexity measurement tool, SCARE, for static C source code. WP07 has also studied means for teaching Trust as in rules applicable to computer heuristics.

Certification is done on a given version of some product upon request. CC certification has already been done on some OS, especially when they are safety or mission critical (for instance, RTOS). But when dealing with open-source software, certification is much harder. SUSE has investigated remaining CC criteria left after D07.1 and has concluded about the impossibility to certify the entire XEN hypervisor due to the non-observance of CC design criteria.

In co-operation with ISECOM and CEA, HPLB participated in investigation on additional quantitative metrics for the OSSTMM and in the introductory training for this methodology. HPLB co-defined the functional coverage and test set for the automated black- and white box testing of XEN source code and modules. In co-operation with the WP07 leader CEA and WP04 partner CUCL, HPLB contributed to a classification results of automated testing to improve their the further development of the XEN code base.

WP07 has also followed closely the OS developments done by the WP04 and WP06 partners, to understand the nature of the developments and ensure that the WP07 support activities remain helpful to these developments.

2.2 Targets analyses

The WP07 activities provide support to the development activities of WP05 and WP06 and therefore has investigated which targets are important to address and support. It was considered since the beginning of the project, that stable components are to be addressed first, followed by components developed along OpenTC. It was also considered that components are to be considered from the bottom layers (close to the hardware) to the upper layer (central OS components). Hardware components, such as the TPM or CPU are out of the scope of this project, as we deal with software items only.

During the first year we have considered that the virtualization layers, namely XEN and L4/Fiasco, are quite stable and merit that we V&V them. Below these, we find BIOSes and boot loaders, that are critical components too, but that are not always open source. We will address the bootloader OSLO during year 3. On top of the central security TPM component, OpenTC has developed in WP03 the TSS, which has been another target for V&V.

Year 2 has therefore concentrated on XEN and the TSS, and year 3 will consider parts of the other items mentioned above.

2.3 Structure of this report

This report is structured along the technical research areas, presenting them in details and giving the reader an insight into the techniques, and also presenting the main results. Some detailed results, particularly those related to static analysis, are moved to appendixes.

Whenever possible, each research task will be described using the following same model:

- **Overview o**f the task, description of its aims and relationship with the original plans of WP07 and its SWP. This introduces the task and binds it to the first workplan (see annex 1 of the OpenTC contract).

- **Technical background**: this contains basic technical elements for the reader to understand the results. Indeed, some tasks are quite new, and some material is given for the reader to understand where the progress lies.
- A detailed description of the **research done**: this is the core part, highlighting the main technical results.
- **On-going work**, to give some perspectives on what will be done during the next project period and what research directions will be taken in that time frame.

3 Development of security and trust metrics

3.1 Overview

In the creation of a trusted system, one must trust the components of the system, trust the operation of those components in an interactive scenario with each other and with the user, and trust the integrity of the components alone or together operating within a specific environment. No methodology has previously existed which could allow this. No metrics have existed to describe this or allow for one system to be compared to another or for operation within a particular environment.

Within OpenTC, ISECOM has been studying and defining the tests and metrics required to accomplish this task. The first year, ISECOM devoted research to the completion of a full security audit and unbiased metrics to facilitate the scientific, operational security testing of OpenTC components as well as define which components must be tested. The second year has focused on research towards defining Trust more completely, trust tests, integrity tests, trust metrics, and security complexity metrics of static source code.

As of this moment, ISECOM has published the penultimate draft of the Open Source Security Testing Methodology Manual (OSSTMM) 3 which comprises of the full requirements for completing an operational security audit and creating unbiased metrics, the Source Code Analysis Risk Evaluation (SCARE) metric and tool for calculating operational security complexity (aka “how complicated is it to secure this software and how volatile is it?”) for the C programming language as well as the means to apply it to others, tested three versions of the XEN source code, and published a draft on defining and measuring Trust.

However, what we have completed is a small portion of what we have done. For this year ISECOM has researched the following:

- We ran various studies and seminars regarding the security testing metrics and defined it mathematically to further its application.
- We have researched an better Trust definition, the elements that form Trust and a metric to represent it as an unambiguous amount.
- We have mapped test types as required to run against the TC system to measure its level of trust and security.
- We have defined a process for measuring security complexity metrics in source code, and have applied it to the C programming language.
- A tool has been written to perform the tasks of the security complexity metric and is being tested.
- The progress of security complexity in XEN by measuring 3 versions of the source code under SCARE.
- The progress of security complexity in the Linux Kernel and how to accurately measure it under SCARE.

3.2 Technical background

“Security Testing” is an umbrella term to encompass all forms and styles of security tests from the intrusion to the hands-on audit. The application of the methodology from this manual will not deter from the chosen type of testing.

Practical implementation of this methodology requires defining individual testing practices to meet the requirements defined here. This means that even when following this methodology, the application of it, the technique, will reflect the type of test one has chosen to do. However, regardless if the test type is blind, double blind, gray box, double gray box, tandem, or reversal, the test must be indicative of the target's ability to operate adequately.

Why test operations? Unfortunately, not everything works as configured. Not everyone behaves as trained. Therefore the truth of configuration and training is in the resulting operations.

This security testing methodology is designed on the principle of verifying the security of operations. While it may not always test processes and policy directly, a successful test of operations will allow for analysis of both direct and indirect data to study the gap between operations and processes. This will show the size of the rift between what management expects of operations from the processes they developed and what is really happening. More simply put, the auditor's goal is to answer: how do current operations work and how do they work differently from how management thinks they work?

The security testing process is a discrete event test of a dynamic, stochastic system. The target is a system, a collection of interacting and co-dependent processes, which is also influenced by the stochastic environment it exists in. Being stochastic means the behaviour of events in a system cannot be determined because the next environmental state can only be partially but not fully determined by the previous state. The system contains a finite, possibly extremely large, number of variables and each change in variable presents an event and a change in state. Since the environment is stochastic, there is an element of randomness and there is no means for predetermining with certainty how all the variables will affect the system state. A discrete test examines these states within the dynamic system at particular time intervals. Monitoring operations in a continuous manner, as opposed to a discrete one, would provide far too much information to analyse. Nor may it even be possible. Even continuous tests however, require tracking each state in reference to time in order to be analysed correctly.

A point of note is the extensive research available on change control for processes to limit the amount of indeterminable events in a stochastic system. The auditor will often attempt to exceed the constraints of change control and present “what if” scenarios which the change control implementers may not have considered. A thorough understanding of change control is essential for any auditor.

An operational security test therefore requires a thorough understanding of the testing process, choosing the correct the type of test, recognizing the test channels and vectors, defining the scope according to the correct index, and applying the methodology properly.

Strangely, nowhere besides in security testing is the echo process considered the defacto test. Like yelling into a cavernous area and awaiting the response, the echo process requires agitating and then monitoring emanations from the target for indicators of a particular state (secure or insecure, vulnerable or protected, on or off, left or right). The echo process is of the cause and effect type of verification. The auditor makes the cause and analyzes the effect from the target. It is strange that this is the primary means of testing something as critical as security because although it makes for a very fast test, it is also highly prone to errors, some of which may be devastating to the target. Consider that in a security test using the echo process it means that should the target not respond then it is secure. Following that logic, a target need only be not interactive to give the appearance of security.

If hospitals used the echo process to determine the health of an individual, it would rarely help people but at least the waiting room time would be very short. Hospitals however, like most other scientific industries, apply the Four Point Process which includes a function of the echo process called the “interaction” as just one of the four tests where the other three are: the “inquest” of reading emanations from the patient (such as pulse, blood pressure, and brain waves), the “intervention” of changing and stressing operating conditions (changing the patient's homeostasis, behavior, routine, or comfort level), and the “induction” of examining the environment as to how it affected the target (analyzing what the patient has interacted with: touched, eaten, drank, breathed in, etc.). However in security testing, the majority of tests are of the echo process alone. There is so much information lost in such one-dimensional testing we should be thankful that the healthcare industry has evolved past just the “Does it hurt if I do this?” manner of diagnosis.

The security test process in this methodology does not recommend the echo process alone for reliable results. While the echo process may be used for certain, particular tests where the error margin is small and the increased efficiency allows for time to be moved to other time-intensive techniques, it is not recommended for tests outside of a deterministic environment. The auditor must choose carefully when and under what conditions to apply the echo process.

While many testing processes exist, the Four Point Process for security testing is designed for optimum efficiency, accuracy, and thoroughness to assure test validity and minimize errors in uncontrolled and stochatic environments. It is optimized for real-world test scenarios outside of the lab. And while it also uses agitation, it differs from the echo process in that it allows for determining more than one cause per effect and more than one effect per cause.

The Four Points

1. **Induction**: establishing principle truths about the target from environmental laws and facts.
2. **Inquest**: investigating target emanations.
3. **Interaction:** like echo tests, standard and non-standard interactions with the target to trigger responses.
4. **Intervention**: changing resource interactions with the target or between targets.

Point 1, the Induction Phase

The auditor determines factual principles regarding the target from the environment where the target resides. As the target will be influenced by its environment, its behavior will be determinable within this influence. Where the target is not influenced by its environment but should exists an anomaly to be understood.

Point 2, the Inquest Phase

The auditor investigates the emanations from the target and any tracks or indicators of those emanations. A system or process will generally leave a signature of its existence through interactions with its environment.

Point 3, the Interaction Phase
The auditor will inquirey or agitate the target to trigger responses for analysis.

Point 4, the Intervention Phase
The auditor will intervene with the resources the target requires from its environment or from its interactions with other targets to understand the extremes under which it can continue operating adequately.

An audit according to this methodology will require that the full 4 Point Process security tests are completed thoroughly. It will not be possible to follow the full methodology with just the Interaction tests.

3.3 Security Metrics

The completion of a thorough security audit has the advantage of providing accurate metrics on the state of security. The less thorough the audit means a less accurate overall metric. Alternately, lesser skilled auditors and lesser experienced analysts will also adversely affect the quality of the metric. Therefore, a successful metric of security requires an audit which can be described as testing (measuring) from the appropriate vectors required while accounting for inaccuracies and misrepresentations in the test data and skills or experience of the security professionals performing the audit. Faults in these requirements will result in lower quality measurements and false security determinations.

This methodology refers to metrics as **Risk Assessment Values** (RAVs). While not a risk assessment in itself, an audit with this methodology and the RAVs will provide the factual basis for a more accurate and more complete risk assessment.

Overview

Appropriate security metrics require overcoming the bias of common metrics where measurements are generally based on opinions. By not measuring the typical qualitative assessment we can begin to factually quantify security. The further we can remove the emotional element from the security test, the more accurately the metrics will represent the situation.

Applying Risk Assessment Values

This methodology will define and quantify three areas within the scope which together create the big picture defined as Actual Security as its relevance to the current and real state of security. The big picture approach is to calculate separately as a condensed value, each of the areas: Operations, Controls, and Limitations. The 3 values are combined and further condensed to form the fourth value, Actual Security, to provide the big picture overview and a final metric for comparisons. Since the RAV is relevant security information condensed it is extremely scalable. This allows for comparable values between two or more scopes regardless of the number of targets, vector, test type, or index where the index is the method of how individual targets are calculated. This means that with RAVs the security of a single target can be realistically compared with 10,000 targets.

One important rule to applying these metrics is that Actual Security can only be calculated per scope. A change in channel, vector, or index is a new scope and a new calculation for Actual Security. However, multiple scopes can be calculated together to create one Actual Security that represents a fuller vision of operational security. For example, the audit will be made of internet-facing servers from both the internet side and from within the perimeter network which they reside. That is 2 vectors. The first vector is indexed by IP address and contains 50 targets. The second vector is indexed by MAC address and is 100 targets. Once each audit is completed and metrics are counted for each of the 3 areas, they can be combined into one calculation of 150 targets and the sums of each area. This will give a final Actual Security metric which is much more complete for that perimeter network then either would be alone.

The use of the RAVs requires understanding this specific terminology and current security research. This terminology provides a specific means to describe quantified security. Without such exact definitions it is not possible to convey the meaning without referring to the process of obtaining the numbers.

Table 1: Terminology

Term	Definition
Security	A form of protection where a physical separation is created between the assets and the threat. In order to be secure, either the asset is physically removed from the threat or the threat is physically removed from the asset. This includes elimination of either the asset or the threat. This manual covers security from an operational perspective which is verifying security measures in an operating or live environment.
Safety	A form of protection where the threat or its effects are controlled. In order to be safe, the threat must be identified and the controls must be in place to assure the threat itself or the effects of the threat are minimized to an acceptable level by the asset owner or manager. This manual covers safety as "controls" which is the means to mitigate risk in an operational or live environment.
Operations	The lack of security one must have to be interactive, useful, public, open, or available. For example, limiting how a person buys goods or services from a store over a particular channel, such as 1 door for going in and out, is a method of security within the store's operations. Operations are defined by visibility, trusts, and accesses.
Controls	Impact and loss reduction controls. The assurance that the physical and information assets as well as the channels themselves are protected from various types of invalid interactions as defined by the channel. For example, insuring the store in the case of fire is a control that does not prevent the inventory from getting damaged or stolen but will pay out equivalent value for the loss. There are 10 controls. The first five controls are Class A which control interactions. The five class B controls are relevant to controlling procedures.
Limitations	This is the current state of perceived and known limits for channels, operations, and controls as verified within the audit. For example, an old lock that is rusted and crumbling used to secure the gates of the store at closing time has an imposed security limitation where it is at a fraction of the protection strength necessary to delay or withstand an attack. Determining that it is old and weak through visual verification in this case is referred to as an identified limitation. Determining it is old and weak by breaking it using 100 kg of force when a successful deterrent requires 1000 kg of force shows a verified limitation.

Operational Security

Operational Security also known as the scope's Porosity is the first of the three RAV factors that should be determined. It is initially measured as the sum of the scope's visibility, access and trust ($OpSec_{sum}$).

When we want to calculate the Risk Assessment Value it is however necessary to determine the Operational Security base value, $OpSec_{base}$. The Operational Security base value is given by the equation

$$OpSec_{base} = \left(\log 10 \times \left(1 + \left(OpSec_{sum} \times 100\right)\right)\right)^2 .$$

To measure the security of operations (OPSEC) requires the measurements of visibility, trust, and access from the scope. The number of targets in the scope that can be determined to exist by direct interaction, indirect interaction, or passive emanations is its **visibility**. As visibility is determined, its value represents the number of targets in the scope. Trust is any non-authenticated interaction to any of the targets. Access is the number of interaction points with each target. The sum of all three is the OPSEC Delta, which is the total number of openings within operations and represents the total amount of operational security decreased within the target.

Table 2: Calculating OPSEC

OPSEC Categories	Descriptions
Visibility	The number of targets in the scope according to the scope. Count all targets by index only once and maintain the index consistently for all targets. It is generally unrealistic to have more targets visible then are targets in the defined scope however it may be possible due to vector bleeds where a target which is normally not visible from one vector is visible due to a misconfiguration or anomaly. A HUMSEC audit employs 50 people however only 38 of them are interactive from the test vector and channel. This would make a visibility of 38.
Trust	Count only each target allowing for unauthenticated interaction according to the scope. A HUMSEC audit may reveal that the help desk employees grant password resets for all calls coming from internal phones without requesting identifying or authorizing information. Within this context, each help desk employee who does this is counted as a Trust for this scope. However, the same cannot be held true for external calls as in that different scope, the one with the external to internal vector, these same help desk employees are not counted as trusts.
Access	This is different from visibility where one is determining the number of existing targets. Here the auditor must count each Access per unique interaction point per unique probe. In a PHYSSEC audit, a building with 2 doors and 5 windows which all open has an Access of 7. If all the doors and windows are sealed then it is an Access of 0 as these are not points where one can gain entry. For a COMSEC audit of data networks, the auditor counts each port response as an Access regardless how many different ways the auditor can probe that port. However, if a service is not hosted at that port (daemon or an application) then all replies come from the IP Stack. Therefore a server that responds with a SYN/ACK and service interactivity to 1 of the TCP ports scanned and with a RST to the rest is not said to have an access count of 65536 (including port 0) since 66535 of the ports respond with the same response of RST which is from the kernel. To simplify, count uniquely only ports with

	service responses and IP Stack responses only when the probe initiates service interactivity. A good example of a service activity over the IP Stack is an ICMP echo response (PING reply). With HUMSEC audits, this is much more simplified. A person who responds to a query counts as an access with all types of queries (all the different questions you may ask or statements made count as the same type of response on the same channel). Therefore a person can only be an Access of 1 per channel and vector. Only a person who completely ignores the request by not acknowledging the channel is not counted.
OPSEC Delta	Visibility + Trust + Access The negative change in OPSEC protection.

Controls

The next step in calculating the RAV is to define the Loss Controls; the security mechanisms put in place to protect the operations. First the sum of the Loss Controls, LC_{sum}, must be determined by adding together the 10 Loss Control categories. Now, the Controls base value can be calculated as

$$LC_{base} = \left(\log 10 \times \left(1 + \left(LC_{sum} \times 10\right)\right)\right)^2 .$$

The LC_{sum} is multiplied by 10 here as opposed to 100 in the Operational Security equation to account for the fact that all 10 Loss Controls are necessary to fully protect 1 visibility, access or trust.

Missing Controls

Given that the combination of the 10 Loss Controls combined balance the value of 1 OpSec loss (visibility, access, trust) it is necessary to determine the amount of Missing Controls, MC_{sum}, in order to assess the value of the Security Limitations. This must be done individually for each of the 10 Loss Control categories. For example, to determine the Missing Controls for Authentication (MC_{Auth}) we must subtract the sum of Authentication Controls ($Auth_{sum}$) of the scope from the $OpSec_{sum}$. The Missing Controls can never be less than zero however.

The equation for determining the Missing Controls for Authentication (MC_{Auth}) is given by

$$MC_{Auth} = OpSec_{sum} - Auth_{sum} .$$

If $OpSec_{sum} - Auth_{sum} \leq 0$

then $MC_{Auth} \approx 0$.

The resulting Missing Control totals for each of the 10 Loss Controls must then be added to arrive at the total Missing Control value (MC_{sum}).

Controls are the 10 loss protection categories in two categories, Class A (interactive) and Class B (process). The Class A categories are authentication, indemnification, subjugation, continuity, and resilience. The Class B categories are non-repudiation, confidentiality, privacy, integrity, and alarm.

Class A

- Authentication is the control of interaction requiring having both credentials and authorization where identification is required for obtaining both.
- Indemnification is the control over the value of assets by law and/or insurance to recoup the real and current value of the loss.
- Subjugation is the locally sourced control over the protection and restrictions of interactions by the asset responsible.
- Continuity is the control over processes to maintain access to assets in the events of corruption or failure.
- Resilience is the control over security mechanisms to provide protection to assets in the event of corruption or failure.

Class B

- Non-repudiation prevents the source from denying its role in any interactivity regardless whether or not access was obtained.
- Confidentiality is the control for assuring an asset displayed or exchanged between parties can be known outside of those parties.
- Privacy is the control for the method of how an asset displayed or exchanged between parties can be known outside of those parties.
- Integrity is the control of methods and assets from undisclosed changes.
- Alarm is the control of notification that OPSEC or any controls have failed, been compromised, or circumvented.

Table 3: Calculating Controls

Controls Categories	Descriptions
Authentication	Count each instance of authentication required to gain access. This requires that authorization and identification make up the process for the proper use of the authentication mechanism. In a PHYSSEC audit, if both a special ID card and a thumb print scan is required to gain access then add two for authentication. However if access just requires one or the other then only count one.
Indemnification	Count each instance of methods used to exact liability and insure compensation for all assets within the scope. A basic PHYSSEC example is a warning sign threatening to prosecute trespassers. Another common example is property insurance. In a scope of 200 computers, a blanket insurance policy against theft applies to all 200 and therefore is a count of 200. However, do not confuse the method with the flaw in the method. A threat to prosecute without the ability or will to prosecute is still an indemnification method however with a limitation.

Subjugation	Count each instance for access or trust in the scope which strictly does not allow for controls to follow user discretion or originate outside of itself. This is different from being a security limitation in the target since it applies to the design or implementation of controls. In a COMSEC data networks audit, if a login can be made in HTTP as well as HTTPS but requires the user to make that distinction then it fails to count toward Subjugation. However, if the implementation requires the secured mode by default such as a PKI-based internal messaging system then it does meet the requirement of the Subjugation control for that scope. More simply, in HUMSEC, a non-repudiation process where the person must sign a register and provide an identification number to receive a document is under Subjugation controls when the provider of the document records the identification number rather than having the receiver do so to eliminate the recording of a false number with a false name.
Continuity	Count each instance for access or trust in the scope which assures that no interruption in interaction over the channel and vector can be caused even under situations of total failure. Continuity is the umbrella term for characteristics such as survivability, load balancing, and redundancy. In a PHYSSEC audit, it is discovered that if an entry way into a store becomes blocked no alternate entry way is possible and customers cannot enter therefore the access does not have Continuity. In a COMSEC data networks audit, if a web server service fails from high-load then an alternate web server provides redundancy so no interactions are lost. This access does have Continuity.
Resilience	Count each instance for access or trust in the scope that does not fail open and without protection or provide new accesses upon a security failure. In common language, it is said to “fail securely”. In a PHYSSEC audit, from 2 guards controlling access to a door if one is removed in any way, then the door cannot be opened by the remaining guard then it has Resilience. In a COMSEC data networks audit, if a web service requiring a login or password loses communication with its authentication database, then all access should be denied rather than permitted to have Resilience.
Non-repudiation	Count each instance for the access or trust that provides a non-repudiation mechanism for each interaction to provide assurance that the particular interaction did occur at a particular time between the identified parties. Non-repudiation depends upon identification and authorization to be properly established for it to be properly applied without limitations. In a PHYSSEC audit, the Non-repudiation control exists if the entrance to a building requires a camera with a biometric face scan to gain entry and each time it is used, the time of entry is recorded with the ID. However, if a key-card is used instead, the Non-repudiation control, requires a synchronized, time-coded camera to assure the record of the card-users identity to avoid being a flawed implementation. If the door is tried without the key card, not having the synchronized camera monitoring the door would mean that not all interactions with the entryway have the Non-repudiation control and therefore does not count for this control. In a COMSEC data networks audit, there may be multiple log files for non-repudiation. A port scan has interactions at the IP Stack and go into one log while interaction with the web service would log to another file. However, as the web service may not log the interactions from the POST method, the control is still counted however so is the security limitation.

Confidentiality	Count each instance for access or trust in the scope that provides the means to maintain the content of interactions undisclosed between the interacting parties. A typical tool for Confidentiality is encryption. Additionally, obfuscation of the content of an interaction is also a type of confidentiality albeit a flawed one. In HUMSEC, however, a method of Confidentiality may include whispering or using hand signals.
Privacy	Count each instance for access or trust in the scope that provides the means to maintain the method of interactions undisclosed between the interacting parties. While “being private” is a common expression, the phrase is a bad example of what privacy is as a loss control because it includes elements of confidentiality. As a loss control, when something is done “in private” it means that only “the doing” is private but the content of the interaction may not be. A typical tool for Privacy is opaquing the interaction, having the interaction take place outside of the Visibility of third parties. Confusion of the means of interaction as obfuscation is another method of applying the Privacy control. In HUMSEC, a method of Privacy may be simply taking the interaction into a closed room away from other people. In movies, we see techniques to create the Privacy control such as setting two of the same suitcases set side by side, some type of incident to create confusion takes place and the two people switch the suitcases in seemingly plain view.
Integrity	Count each instance for access or trust in the scope which can assure that the interaction process and access to assets has finality and cannot be corrupted, hanged, continued, redirected, or reversed without it being known to the parties involved. Integrity is a change control process. In COMSEC data networks, encryption or a file hash can provide the Integrity control over the change of the file in transit. In HUMSEC, segregation of duties and other corruption-reduction mechanism provide Integrity control. Assuring integrity in personnel requires that two or more people are required for a single process to assure oversight of that process. This includes that no master access to the whole process exists. This can be no person with full access and no master key to all doors.
Alarm	Count each instance for access or trust which has a record or makes a notification when unauthorized and unintended porosity increases for the vector or restrictions and controls are compromised or corrupted. In COMSEC data networks, count each server and service which a network-based intrusion detection system monitors. Or count each service that maintains a monitored log of interaction. Access logs count even if they are not used to send a notification alert immediately unless they are never monitored. However, logs which are not designed to be used for such notifications, such as a counter of packets sent and received, does not classify as an alarm as there is too little data stored for such use.
Controls Delta	Sum (all controls) *.1 The positive change over OPSEC protection. The 10 loss controls combined balance the value of 1 OPSEC loss (access, visibility, or trust).

Security Limitations

The state of security in regard to known flaws and protection restrictions within the scope are calculated as Limitations. To give appropriate values to each limitation type, they must be categorized and classified. While any classification name or number can be used, this methodology attempts to name them according to their effects on OPSEC and Controls and does not regard them in a hierarchical format of severity. Five classifications are designated to represent all types of limitations.

1. Vulnerability is a flaw or error that: (a) denies access to assets for authorized people or processes, (b) allows for privileged access to assets to unauthorized people or processes, or (c) allows unauthorized people or processes to hide assets or themselves within the scope.
2. Weakness is a flaw or error that disrupts, reduces, abuses, or nullifies specifically the effects of the interactivity controls authentication, indemnification, resistance, subjugation, and continuity.
3. Concern is a flaw or error that disrupts, reduces, abuses, or nullifies the effects of the flow or execution of process controls non-repudiation, confidentiality, privacy, integrity, and alarm.
4. Exposure is an unjustifiable action, flaw, or error that provides direct or indirect visibility of targets or assets within the chosen scope channel of the security presence.
5. Anomaly is any unidentifiable or unknown element which cannot be accounted for in normal operations.

The concept that limitations are only limitations if they have no justification in business or otherwise is false. A limitation is a limitation if it behaves in one of the limiting factors as described here. A justification for a limitation is a risk decision and one that is either met with a control of some kind even if that control is merely acceptance. Risk decisions that accept the limitations as they are often come down to: the damage a limitation can do does not justify the cost to fix or control the limitation, the limitation must be so according to legislation, regulations, or policy, or a conclusion that the threat does not exist or is likely for the particular limitation. Risk justifications do not enter in the RAV metrics and all limitations should be counted as discovered regardless if best practice, common practice, or legal practice denotes it as not an acceptable risk. For the metric to be a true representation of the operational security of the scope, for the ability of future risk assessments to be performed with the metric as a basis, and for proper controls to be used to offset even those risks deemed necessary for legislative reasons, the auditor must report the operational security state as it is.

Another concept that must be taken into consideration is one of managing flaws and errors in an audit. An audit will often uncover more than one flaw per target. The auditor is to report the flaws per target and not the weak targets. These flaws may be in the protection measures and controls themselves diminishing actual security. Each flaw is to be rated as to what occurs when the flaw is invoked even if that must be theoretical or of limited execution to restrict actual damages. Theoretical categorization, where operation could not take place, is a slippery slope and should really only be limited in the case of a medium to high risk of actual damages or where recovery from damage is difficult or requires a long time period. When categorizing the flaws, each flaw should be examined and calculated in specific terms of operation at its most basic components. However, the auditor should be sure never to report a “flaw within a flaw” where the flaws share the same component and same operational effect.

The Security Limitations are individually weighted. The weighting of the Vulnerabilities, Weaknesses and Concerns are based on a relationship between the Porosity or $OpSec_{sum}$ and the Loss Controls.

The following value table is used to calculate the $SecLim_{sum}$ variable, as an intermediate step between the Security Limitation inputs and the $SecLim_{base}$ variable, which is the Security Limitations basic input for the RAV equation.

Input	Weighted Value	Variables
Vulnerability	$(\log 10(OpSec_{sum} + MC_{sum})) + 1$	MC_{sum} : sum of Missing Controls
Weakness	$(\log 10(OpSec_{sum} + MC_{A})) + 1$	MC_{A} : sum of Missing Controls in Control Class A
Concern	$(\log 10(OpSec_{sum} + MC_{B})) + 1$	MC_{B} : sum of Missing Controls in Control Class B
Exposure	$(\log 10(V)) + 1$	V : sum of Visibility
Anomaly	$(\log 10(V + MCa)) + 1$	V : sum of Visibility MC_{A} : sum of Missing Controls in Control Class A

Security Limitations Base

$SecLim_{sum}$ is then calculated as the aggregated total of each input multiplied by its corresponding weighted value as defined in the table above. The Security Limitations base equation is given as:

$$SecLim_{base} = (\log 10 \times (1 + (SecLim_{sum} \times 100)))^2$$

Table 4: Calculating Security Limitations

Limitations Categories	Auditing and Examples
Vulnerability	Count separately each flaw or error that that defies protections whereby a person or process can access, deny access to others, or hide itself or assets within the scope. In PHYSSEC, a vulnerability can be such things as a simple glass door, a metal gate corroded by the weather, a door that can be sealed by wedging coins into the gap between it and its frame, electronic equipment outdoors not sealed from pests such as ants or mice, a bootable cd-rom drive on a PC, or a process that allows an employee to take a trashcan large enough to hide or transport assets out of the scope. In HUMSEC, a vulnerability can be a cultural bias that does not allow an employee to question others who do not look like they belong there or a lack of training which leaves a new secretary to give out business information classified for internal use only to a caller. In COMSEC data security, a vulnerability can be such things as a flaw in software that allows an attacker to overwrite memory space to gain access, a computation flaw that allows an attacker to lock the CPU into 100% usage, or an operating system that allows enough data to be copied onto the disk until it itself can't operate anymore. In COMSEC telecommunications, a vulnerability can be a flaw in the pay phone system that allows sounds through the receiver mimic coin drops, a telephone box that allows anyone to access anyone else's phone line, a voice mail system that provides messages from any phone anywhere, or a FAX machine that can be polled remotely to resend the last thing in memory to the caller's number. In SPECSEC, a vulnerability can be hardware which can be overloaded and burnt out by higher powered versions of the same frequency or a near frequency, a standard receiver without special configuration which can access the data in the signal, a receiver which can be forced to accept a third-party signal in place of the intended one, or a wireless access point dropping connections from a nearby microwave oven.
Weakness	Count each flaw or error in the controls for interactivity: authentication, indemnification, resistance, subjugation, and continuity. In PHYSSEC, a weakness can be such things as a door lock that opens when a card is wedged between it and the door frame, a back-up generator with no fuel, or insurance that doesn't cover flood damage in a flood zone. In HUMSEC, a weakness can be a process failure of a second guard to take the post of the guard who runs after an intruder or a cultural climate within a company for allowing friends into posted restricted spaces. In COMSEC data security, a weakness can be such things as login that allows unlimited attempts or a web farm with round-robin DNS for load balancing although each system has also a unique name for direct linking. In COMSEC telecommunications, a weakness can be a flaw in the PBX that has still the default administration passwords or a modem bank for remote access dial-in which does not log the caller numbers, time, and duration. In SPECSEC, a weakness can be a wireless access point authenticating users based on MAC addresses or a RFID security tag that no longer receives signals and therefore fails “open” after receiving a signal from a high power source.

Concern	Count each flaw or error in process controls: non-repudiation, confidentiality, privacy, integrity, and alarm. In PHYSSEC, a concern can be such things as a door lock mechanism whose operation controls and key types are public, a back-up generator with no power meter or fuel gage, an equipment process that does not require the employee to sign-out materials when received, or a fire alarm not loud enough to be heard by machine workers with ear plugs. In HUMSEC, a concern can be a process failure of a guard who maintains the same schedule and routine or a cultural climate within a company that allows employees to use public meeting rooms for internal business. In COMSEC data security, a concern can be the use of locally generated web server certificates for HTTPS or log files which record only the transaction participants and not the correct date and time of the transaction. In COMSEC telecommunications, a concern can be the use of a FAX machine for sending private information or a voice mail system that uses touch tones for entering a PIN or password. In SPECSEC, a concern can be a wireless access point using weak data encryption or an infrared door opener that cannot read th sender in the rain.
Exposure	Count each unjustifiable action, flaw, or error that provides direct or indirect visibility of targets or assets within the chosen scope channel of the security presence. In PHYSSEC, an exposure can be such things as a window which allows one to view assets and processes or an available power meter that shows how much energy a building uses and its fluctuation over time. In HUMSEC, an exposure can be a guard who allows all visitors to view the sign-in sheet with all the other visitors listed on it or a company operator who informs callers that a particular person is out sick or on vacation. In COMSEC data security, an exposure can be a descriptive and valid banner about a service (disinformation banners are not exposures) or a ICMP echo reply from a host. In COMSEC telecommunications, an exposure can be an automated company directory sorted by alphabet allowing anyone to cycle through all persons and numbers or a FAX machine that stores the last dialed numbers. In SPECSEC, an exposure can be a signal that disrupts other machinery announcing its activity or an infrared device whose operation is visible by standard video cameras with night capability.

Anomaly	Count each unidentifiable or unknown element which cannot be accounted for in normal operations, generally when the source or destination of the element cannot be understood. An anomaly may be an earl sign of a security problem. Since unknowns are elements which cannot be controlled for, a proper audit requires noting any and all anomalies. In PHYSSEC, an anomaly can be dead birds discovered on the roof a building around communications equipment. In HUMSEC, an anomaly can be questions a guard asks which may seem irrelevant to either the job or standard small talk. In COMSEC data security, an anomaly can be correct responses to a probe from a different IP address than was probed or expected. In COMSEC telecommunications, an anomaly can be a modem response from a number that has no modem. In SPECSEC, an anomaly can be a powerful and probably local signal that appears once momentarily but not long enough to locate the source.

Actual Security

To measure the current state of operations with applied controls and discovered limitations, a final calculation is required to define Actual Security. As implied by its name this is the whole security value which combines the three values of operational security, controls, and limitations to show the actual state of security.

The purpose of Actual Security is to condense the three combined values into a simple metric value percentile that can be used to rate operational security effectiveness and provide a method of comparison, scoring, and rating. This big picture approach is effective because it does not simply show how one is prepared for threats but how effective one's preparations are against threats.

Table 5: Calculating Actual Security

Actual Security Categories	**Descriptions**
Actual Delta	The actual security delta is the sum of Op Sec Delta and Loss Controls Delta and subtracting the Security Limitations Delta. The Actual Delta is useful for comparing products and solutions by previously estimating the change (delta) the product or solution would make in the scope.
Actual Security (Total)	Actual security is the true (actual) state of security provided as a hash of all three sections and represented in a percentage where 100% represents a balance of controls for interaction points to assets with no limitations.

The Actual Delta is useful for comparing products and solutions by previously estimating the change (delta) the product or solution would make in the scope. We can find the Actual Security Delta, $ActSec\Delta$, with the formula:

$$ActSec\Delta = LC_{base} - OpSec_{base} - ActSec_{base}\ .$$

To measure the current state of operations with applied controls and discovered limitations, a final calculation is required to define Actual Security. As implied by its name this is the whole security value which combines the three values of operational security, controls, and limitations to show the actual state of security.

Actual Security (total), $ActSec$, is the true state of security provided as a hash of all three sections and represented in a percentage where 100% represents a balance of controls for interaction points to assets with no limitations. The final RAV equation for Actual Security is given as:

$$\begin{aligned}
&ActSec = \left(100 - OpSec_{base}\right) \\
&+ \left(100 - \left(OpSec_{base}\right) \times \left(LC_{base} \times .01\right)\right) \\
&- \left(\left(100 - \left(OpSec_{base}\right) + \left(LC_{base}\right)\right) \times \left(ActSec_{base} \times .01\right)\right)
\end{aligned}$$

3.4 Trust metrics

AVIT, the Applied Verification for Integrity and Trust methodology will be both a sequence of proper and thorough testing as well as a guide for the application of trust. A methodology is useful reproducibility is a key component to a task. An open methodology is necessary when the means of reproducing the results must be transparent. This methodology, AVIT, the Applied Verification of Integrity and Trust, is a core component of the OpenTC project because the test subject deals with privacy issues therefore the methods of assuring the privacy issues are well tested requires a transparent, reproducible test method. And a strong methodology of operation tests to standardize on should be able to provide meaningful, unbiased metrics.

AVIT follows the work which has been developed for the OSSTMM (Open Source Security Testing Methodology Manual) which is an open, security testing standard. The OSSTMM provides the flexible security testing methodology which can be conformed under AVIT to provide a security test of the full range of OpenTC components, the Linux OS on which it resides, and the networked environment from multiple vectors. Thereby it will allow OpenTC to quantify the integrity and ultimately the trust value of the OpenTC system. Furthermore, it will provide a means and a gage by which the public can understand trust.

The basis to measuring Trust is to relate it to integrity, that thing that tells us something is still “all right”. Integrity is a subset of security. It is a loss control and when applied will determine if a change has occurred, intended or not. Integrity tests will need to be made with the security tests to determine that the system as a whole is mostly free of holes (no porosity) and that this condition does not change with the introduction of the various OpenTC components. A high integrity score should validate that a strong chain of trust is in place meaning that the point of origin and manufacture for each component in the system, either software or hardware, can be identified, verified, and assured that no change has taken place upon the intended, displayed, and non-malicious state of the device.

This means in AVIT in order to show a trust level we need to prove its level of operational integrity. And to prove it's level of integrity we need to determine its level of porosity, the lack of security as a protection mechanism. Therefore the methodology provided by AVIT will consist of:

- Four Point Process: the process of a thorough security test of operations,
- Error Types: the process of recognizing causes of errors in operational tests,
- Security Testing Methodology: the sequence of operational security tests,
- Security Metrics: the means to calculate security,
- Integrity Testing Methodology: the sequence of trust tests,
- Trust Metrics: the means to calculate trust levels based on integrity and security tests

The difficulty of this research and subsequent tests and metrics is in the nature of trust and integrity to be closely tied to security but is also not affected by it should inaccuracies or a high level of porosity be determined within it. Partly this has to do with human psychology and the human irrationality when it comes to trust which is a known element already profitably exploited in advertising, gambling, and politics. Therefore prior studies in psychology, marketing, game theory, economics, and political science are evaluated concurrently with the published articles within the project focus of Trusted Computing.

Current research has shown trust is obtainable quantitatively through the manipulation of several elements known as the Trust Rules. The Trust Rules are:

1. Scope: the superset which contains the target (number of items/people/processes to be trusted) and all of the components of those targets. This defines the scope of trust and all inclusive parts of what needs to be trusted. This is like defining how and where you see a tree where tree is the term for roots, branches, trunk, sap, leaves, and all the other parts that make up a tree.
2. Symmetry of trust: the vector (direction) of the trust. It may be one way (asymmetrical) and defined as to which way the trust must travel or both ways (symmetrical).
3. Transparency: the level of visibility of all parts of the scope and the operating environment of the target.
4. Control: the amount and direction of influence over the scope by the operator(s) (also known as subjugation).
5. Historical consistency: the use of time as a measure of integrity by examining prior operations and behaviours of the target.
6. Integrity: the amount and timely notice of change within the target.
7. Offsets of sufficient assurance: the comparison of the amount that which the value placed within the target to the value of compensation to the operator or punishment to the target should the trust fail.
8. Value of reward: the amount of gain for which trust in the target is sufficient for the risk.
9. Chain of trust: the verification of the origins and influences over the target prior to its current state. The further back to the origins of the target, the greater the likelihood malicious players or foul play can be determined.
10. Adequacy of security, controls, and limitations: the amount and effectiveness of protection levels can tell the actual state of the target's integrity.

A major part of the Trust Rules requires a documented and verifiable process chain starting at the distributors and moving backwards in the process to the manufacturers, coders, and architects. This part of the integrity test alone provides a huge challenge to Open Source software developers as such a process is rarely followed properly. However, without it, there can be only a very short chain of trust and the inability to fully verify integrity.

Interestingly, security, is only a small part within those rules. Rational decision making where it pertains to trust often does not include security because it is often mistakenly confused for feelings of risk and can therefore be often satisfied by rule no. 8. This is notable when we compare trust with security. The need to gain security acceptance, where acceptance is the same goal to achieve as in trust, they follow a pyramid notably similar to the advertising pyramid which categorizes a linear acceptance of a message as such:

1. Awareness --> 2. Comprehension --> 3. Conviction --> 4. Desire --> 5. Action

1. A need for security is communicated in the media or through sales channels which generates awareness, often promoting fear, uncertainty, or doubt (Awareness).
2. The need for security is taught or mandated through regulations and legislation (Comprehension).
3. Incentives and punishments are used to convince the need to apply the appropriate security measures (Conviction).
4. Security becomes desired often as a result of a problem or an unfavorable risk assessment (Desire).
5. Security is seen as necessary and applied with the motivation to maintain security levels (Action).

However, in a trust model, there is no pyramid. It is not linear. There is no building towards trust in a particular order or even an effort value system where it can be determined that one level requires more effort than another. In methodology terms, it appears irrational when calculated. A decision to trust therefore may be concluded by the correct answer from one or more of the following questions which make up the Trust Rules:

1. How many items/people/processes involved must the trust extend to?
2. For each item/people/processes is the trust symmetrical?
3. For each item/people/processes is the process or motives transparent?
4. Which items are under the control of self or a trusted person?
5. For each item/people/processes, how far back (the number of steps) to the last gap is there an historical consistency to the process, people, or items?
6. Is the integrity of the item or process transparent for each?
7. What are the combined value of offsets of sufficient assurance (insurance or leverage) such as reprisals, liens, or harmful penalties which have an acceptable additional cost?
8. How great is the reward/win?
9. How far back (the number of steps) to the beginning or creation of each person, process or item can the chain of trust be established and how many gaps exist in each?
10. What is the value of the Security measures and controls (Safety) subtracting the known Limitations? (see the OSSTMM for the calculation of this metric)

These questions are formed from the Trust Rules which define decision making built on trust. There is no right or wrong answer here because the amount of requirements to trust must only equal or surpass the perceived value of the potential loss. Therefore, only one question must be answered correctly to have sufficient weight to trust.

The challengers of a trust metric say that it is part of human nature and cannot be measured any more than love or hate, of which both can be irrational or impossible to determine the causes thereof. However, where love and hate are emotions, trust is not. It is like safety and security. It is a decision which we can feel for rather than an emotion which we feel. What we find is that as a decision, trust is rationalized by considering some or all of the Trust Rules, depending upon the skill and the experience of the decision maker. But like all decisions, one can choose to go contrary to what the decision making process suggests with varied consequences.

To apply those questions into a metric is another part of this our goals. This is serving to be a very difficult process because it is important to separate quantitative and qualitative questions. And it is our goal to completely eliminate qualitative questions so as to remove bias. Furthermore, as a simple calculation this can quickly fail when one introduces the following resolution:

- Not trusting is not an option.

This is when the only option is to trust because all others end very unfavourably. Decisions based on ultimatums or intimacy are almost always irrational. Hence the plot of many mainstream suspenseful dramas. The challenge is to give the hero a graceful way out of a decision that in reality would spark an irrational action if it were even to get that far. Most viewers would comment that the situation is not realistic or would have been realistically solved at a much earlier stage by confronting the problem. However in a similar situation where one must trust anyway even when the calculations don't balance out with potential loss. It is human nature to disregard or forget the negative in order to avoid drastic change, loss of life, or loss of lifestyle.

So for all the Rules of Trust can provide, the irrational decision made where trust is not an option is a wild card to the equation. For example, in Trusted Computing, the operator may not trust the computer no matter how great the reward may be because of mainstream media and not of a personal distrust or a problem with the security or integrity of the system. It is this final hurdle the OpenTC project must overcome.

The security test and integrity verification on the software code and components to be adhered to the Linux system and hardware are to contribute to the final trust score. While each of the trust tests themselves from the Trust Rules will facilitate the operator's decision process towards an OpenTC system, such as the Demonstrator, on whether to trust or not to trust, comes from the development team. As a methodology, these tests together will make the facilitation of a trust decision easier as it will be a peer-reviewed and standardized means of determining trust which can be applied to any other system claiming to be a Trusted Computer. While this may seem to have little value beyond the justly paranoid or the keepers of information secretive or even just not classified for public knowledge, the markets for those with sensitive information now is quite large and the buyers want transparency of what exactly is being bought and who had their hands on it. The development team's awareness of the Trust Rules and how trust and is evaluated will need to be reflected in the Demonstrator.

Ideally a methodology like AVIT should not only be part of the trust and integrity documentation but also directly built into the system as a form of automatic re-verification. Since the TSS itself should be able to maintain the current integrity and trust level, it should be able to keep track of the whole chain for everything that it is a part of and keep record of all authorized and accepted changes so the system can be transferred while transferring the entire current trusted state. And without our ideals, there would never be the contrast to know what one should strive for.

3.5 Complexity

The **Source Code Analysis Risk Evaluation** (SCARE) project is a study to create a security complexity metric that will analyze source code and provide a realistic and factual representation of the potential of that source code to create a problematic binary. This metric will not say that the binary will be exploited nor does it do a static analysis for known limitations like vulnerabilities. However it will flag code for a particular interaction type or control and allow the developer to understand which OpSec holes are not protected even if it can't say the effectiveness of that protection. The level of required effectiveness would require a much more sophisticated analysis tool and not within the scope of this project at this time.

The goal of this study is to apply the ISECOM research findings for security metrics represented as the Risk Assessment Values (RAVs) in OSSTMM 3.0. These metrics define “security” as the separation between an asset and a threat. Therefore, Operational Security (OpSec) are the “holes” in the wall of protection, Controls are the patches for those holes, and Limitations are the problems and failures within OpSec and the Controls.

More information regarding the RAVs and OSSTMM 3.0 Security Metrics can be found at http://www.isecom.org/ravs.

This computation will provide a final SCARE value, like the RAV, where 100% is the proper balance between controls to OpSec holes and no Limitations. Conversely, less than that shows an imbalance where too few Controls protect OpSec holes or Limitations in OpSec and Controls degrade the security.

Currently, SCARE is designed to work for any programming language. While this methodology shows the C language, we need input and feedback from developers of other languages to expand this further.

OPERATIONAL SECURITY

This is based on the conclusion of an elemental study that mainly shows there are only two ways to steal something: take it yourself (represented by Access) or have someone else do it for you (represented by Trust). The Visibility is the exposure or knowledge that there is something to steal as for any theft, there is required the opportunity to steal. Therefore OpSec is compromised by these three types. To calculate OpSec, these 3 types are subtracted from the whole.

TYPE	DESCRIPTION	ITEMS
Visibility	The number of files that the program puts or changes on the disk temporarily or permanently collectively during install and run-time.	user data (applications), configuration files (/etc), sensitive user data (e.g. credit card #, software serial #), applications.

Access	The number of places where interactions between a user and the system may occur as part of the input/response interaction between them.	1. Direct input from the user from files, system or sockets (gets, fgets, scanf, fscanf, fread, recv, recvfrom, recvmsg). 2. Arguments to main() function. 3. Environment variables that the user may configure and change. 4. Variables which can be passed directly to some other functions, or the program can make copies of those arguments and then manipulate the copies. 5. Mathematical actions taken with user provided values. 6. Some cases of read() syscall except when the user cannot control the data such as when reading from some device. 7. Memory allocation of user-controlled variables 8. Directories and file reads where the user may read, create, change, or rename files (readdir, stat, readlink, fstat, lstat).
Trust	The number of places where interactions between the system, other programs on the system, and the program may occur as part of the input/response interaction between them or within the program itself where that input may be open to manipulation by a user.	1. Wherever the user may influence the executed program or the behaviour of the other endpoint (exec* , pipe). 2. The date and time. 3. Where the object is mapped into memory (mmap).

CONTROLS

This is based on the 10 controls, of both process and interaction controls, which when all combined can protect to the equivalent of operational security. Limitations in the Controls themselves are counted under Limitations.

TYPE	DESCRIPTION	ITEMS
Authentication	The item interactions are filtered or sanitized according to identified interaction types, role, location, actions, users, data types, or data length.	Items for all these controls still require research and input.
Indemnification	The item interactions provide a warning to the user according to legal statutes.	

Resistance	The item interactions are designed to fail in a manner that does not leave the program or system unsecured in the case of an attack via survivability safeguards.	
Subjugation	The item interactions are controlled by the program in the form of selecting within the range of specific, selectable choices.	
Continuity	The item interactions are designed to continue working regardless of failure via a safeguard, back-up, or redundancy.	
Non-repudiation	Interaction with the item is part of a process which includes recording the identification of the user and the interactions.	
Confidentiality	Interaction with the item is part of a process which includes protecting the data or information between them so as to be understandable only to intended parties, systems or components.	
Privacy	Interaction with the item is part of a process which includes protecting the means of the interaction so that how the interaction takes place is not understandable nor predictable to unintended parties, systems or components.	

Integrity	Interaction with the item is part of a process which includes a means for which if the state or meaning of records is changed that change becomes known.	
Alarm	Interaction with the item is part of a process which includes alerting the program owner when attempts to breach security or circumvent controls are detected.	

LIMITATIONS

Where OpSec and Controls fail, these are the classifications for their limitations.

TYPE	DESCRIPTION	ITEMS
Vulnerability	The item contains failures related to providing access, denying access, or hiding information/data within the confines of the system.	Items for all these controls still require research and input.
Weakness	The item contains failures related to the Interactive Controls of Authentication, Indemnification, Resistance Subjugation, and Continuity.	
Concern	The item contains failures related to the Process Controls of Non-Repudiation, Confidentiality, Privacy Integrity, and Alarm.	
Exposure	The item contains failures related to Visibility of assets directly or indirectly of interactions.	

Anomaly	The item does not follow programming protocol and will cause the program to act in strange or erratic ways.	

Using SCARE on XEN

The XEN program is a vital piece of the OpenTC project. Since it's already been tested for bugs and vulnerabilities by other project partners, we felt it was a good place to verify the SCARE metrics because we could then compare them to the actual number of problems found in XEN 3.1.0. We decided to test earlier versions as well to see the trend if the code is getting harder to secure.

version	visibility	access	trust	delta	SCARE
3.0.3_0	1	314	28577	-41.74	**58.26**
3.0.4_1	1	311	31060	-42.21	**57.79**
3.1.0	1	316	33139	-42.57	**57.43**

The SCARE for XEN 3.1.0 source matches the large number of problems found in the source code by other test partners. Further tests against Linux Kernel source code are to follow.

The SCARE is getting progressively worse as more and more Trusts are added (functions and variables manipulable through outside configurations and memory). What is interesting is that if you remove the Trusts (assuming a controlled Trusted Computer system where the user cannot access the places in memory or the configuration files that XEN places) and look only at direct user interactions through inputs then the code got better between 3.03 and 3.04 but then got worse again. XEN is clearly getting more complex and the difference between each version here adds thousands more interactive points to protect. Where complexity is not always bad for security, in this case it clearly is.

3.6 Testing Methodology Improvements

Developing a testing methodology is a straight-forward act which requires thoroughly understanding a subject and all the ways it must be tested to assure it against all the ways it could fail. However, security and trust research are more like philosophies than like hard sciences and just as Aristotle approached physics, we find we need to approach somewhat abstract words like security and trust in a way that satisfies both the "gut feeling" and the facts. Unfortunately, this means that the work done in the investigation of these two topics must be one of evolution as everyone comes to be comfortable with discarding the old views for the newer, more logical ones.

The improvements we must make to the testing methodologies therefore are to constantly strive to prove that all tests have a basis in fact and remove that which has none. This constant tweaking of the methodology will make it stronger but is also difficult to get the world to accept in great leaps. Unfortunately the terminology alone is holding back progress as marketing takes a firmer hold in the user minds than the underlying science can.

3.7 On-going work and future directions

Our on-going future work will be:

- Improving the test methodology and metrics.
- Improving the Trust metrics.
- Finalizing AVIT.
- Automating the search for Controls and Limitations for the C Programming Language in the SCARE tool.
- Applying SCARE to other programming and scripting languages

3.7.1 Applications of Trust metrics and AVIT

Applications of the security and trust metrics are very broad. The means to measure how secure or trustworthy a computer is in a way that can be disseminated is already a large leap of progress. Then to be able to repeat these tests by any other independent lab or even to instil self-checks and diagnostics in computers to perform these checks regularly and automatically will lend to an increased support of transmitting or storing sensitive information using public access ways.

The need for AVIT to be free and open is one of transparency. In order for us to expect to be trusted as developers of a trust test and metric, we need to be open to scrutiny. AVIT is the open public project which will do this and perhaps quell the currently unreasonable hysteria over trusted computing.

4 Dynamic analysis of targets

4.1 Overview

As part of the general V&V efforts of WP7 in OpenTC, BME took on to carry out dynamic analysis, i.e. **security testing on selected modules of OpenTC**. For this purpose a separate sub-workpackage, SWP07a was devoted. The main goal was to create test results in a systematic way, which could be later used for high-assurance Common Criteria evaluations.

Within OpenTC the first year of SWP07a was devoted to the development of the necessary **methodology and tool selection**. Based on an objective market analysis, BME chose the automated security testing tool Flinder for the testing tasks.

In the second year then BME started to use the previously defined methodology to carry out security testing of selected modules of the OpenTC architecture. **In particular BME finished a complete test-correction-validation process on the full API of the IFX TCG Software Stack (TSS) implementation** resulting in approx. 135.000 executed test cases, several found potential vulnerabilities (including remotely exploitable code execution) and a fully validated bugfixed TSS version in the end.

As of the writing of this document, the plans for testing the second target, namely the **XEN hypervisor** are being carried out. Here the goal is to verify that even if attackers can gain control over certain guest domains, other domains (both guests and privileged ones) will be adequately isolated by XEN and thus vulnerabilities can be contained to one virtualized compartment.

Since both CEA and TUS have also carried out evaluations of the XEN hypervisor, an integrated evaluation report and bug list is going to be prepared (in year 3) to demonstrate the collective strength of the different evaluation techniques used and to facilitate the most effective bug fixing and ensure the planned assurance level of the security-critical OpenTC modules.

Conclusions

Based on the results of the completed testing of the IFX TSS implementation, several important conclusions can already be drawn:

- For such complex systems large amounts of resources are needed to carry out a systematic analysis of the implemented functionality. BME carried out approx. 135.000 tests for the coverage of the TSS API, from which only approx. 400 tests (less than 0.3 per cents) yielded potential problems. **Therefore, automated solutions are needed**, which can reliably carry out such a big task.
- The results of the tests showed that a**utomated solutions can detect security-critical programming bugs**, which could compromize the system (e.g. by allowing remote code execution).
- Finally, **we need to use verification and validation techniques**, since even in this case, where a module was clearly designed and implemented with security in mind[1], human mistakes result in vulnerabilities, which could later be

1 During the testing of the IFX TSS implementation BME encountered a ratio of about 0.3 per

used to break the Trusted Computing architecture.

4.2 Technical background

This section details the test process, which will be followed by BME for all testing tasks within OpenTC. Then, a brief overview will be given on the test methodology, which BME established during the first year of the project.

4.2.1 Test process

This section details the test process that BME followed during the execution of testing of the OpenTC Infineon TSS implementation. The following steps constituted to the test process:

1. As the first step Infineon specified the **Target of Evaluation**. The TSS implementation was made available to BME in a state that was suitable for testing.
2. BME created the **Test Plan**, which described the objectives for the testing and the approach chosen for the evaluation. The Test Plan was reviewed by Infineon (being the developer), by CEA (being the leader of workpackage 7 'Software Development Support, Quality, Evaluation and Certification') and by the technical leader of the project. The review of the Test Plan was executed during the telephone conference of January 9, 2007.
3. Based on the Target of Evaluation and the final Test Plan, BME executed the planned tests. As a result BME created an **Internal Test Report**, which contained the detailed descriptions of the test vectors created and the assessments of the reactions of the Target of Evaluation. The Internal Test Report was delivered to the appropriate parties on April 2, 2007.

   Note: The Internal Test Report is strictly confidential. According to the Code of Professional Ethics of ISACA [ISACA-CPE], **BME will report the found vulnerabilities to the appropriate persons only**.
4. Based on the Internal Test Report Infineon carried out **bugfixing** and delivered to BME an updated Target of Evaluation.
5. The **Updated Target of Evaluation** was subject to regression testing.
6. As the final step of the test process BME created the **Pubic Test Report**. This report was again reviewed by Infineon, CEA and the technical leader of the project.

The following figure depicts the schematics of the test process:

cents of failed test cases indicating potential vulnerabilities. This is a much smaller ratio that what is typical in industrial automated security testing of security-critical products (e.g. DRM systems), where the ratio is typically between 10 and 50 per cents.

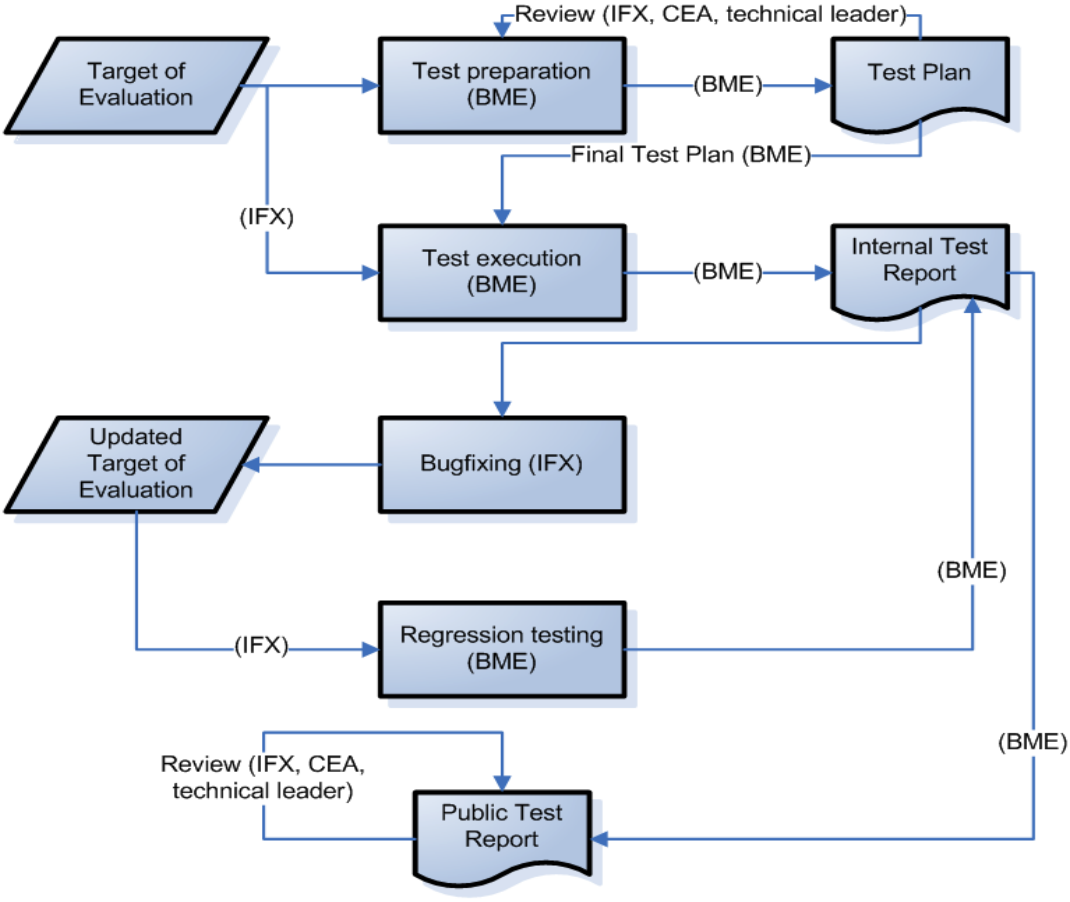


Figure 1: Test process overview

4.2.2 Test methodology

The danger of security-relevant programming bugs is especially high, as vulnerabilities based on these contribute to crucial problems encountered every day in the IT world, such as:

- **exploitable security holes**,
- automatic **intrusions** into critical systems and
- spreading of **viruses**.

The problem is that almost any application can be susceptible to attacks and may be vulnerable. However, it is a common misbelief that combating these vulnerabilities is impossible, since only a very small set of **typical security-relevant programming bugs** is responsible for the vast majority of discovered and exploited vulnerabilities.

The aim of the **automated testing** carried out in the sub-workpackage SWP07a is exactly this: executing test cases aiming to identify typical security-relevant programming bugs in the software packages developed within the OpenTC project and provide the results to the developers in the form of Test Reports.

During the first year of the project BME evaluated 78 tools according to a generic evaluation framework. Ultimately, the decision was to choose the tool called **Flinder**[2]. The main reasons for Flinder after the evaluation of the 78 tools was the following:

- Provided by a reputable vendor (SEARCH-LAB Ltd.) with experiences in security evaluation and testing.
- The tool supported both black-box and white-box testing.
- The tool was provided to BME free of charge to be used within the OpenTC project.
- The tool supported Linux.
- The tool supported regression testing and individual re-run of selected test cases.
- It is possible to create custom modules for special protocols, test algorithms or adaptation to special test environments.

In traditional secure software engineering the emphasis was on formal methods (which could prove the correctness of the applied techniques) and on extensive testing. Flinder's aim is to provide additional help in testing by utilizing a new approach for test vector generation. In our concept the ToE is communicating with an Input Generator via messages. The idea is that Flinder modifies these messages in a man-in-the-middle way. Naturally, this communication can be network-based, but a simple application processing files can also be handled this way.

In order to be able to modify the input messages Flinder needs to know the **format descriptions** of the different messages. Based on the message format descriptions Flinder transforms each message into a general internal format (MSDL). Test specific modifications (so-called **Test Logic**) will work on this internal representation. It is also possible that one test case consists of not just one request-response message exchange, but a series of messages (i.e. execution of a **protocol**) is needed to drive the ToE into the targeted state, and Flinder has to modify the content of a message only then. For testing such protocols, format description of each protocol message and the protocol's state chart need to be given. For this reason Flinder maintains a Protocol Statechart (based on a UML **state machine**), which can describe the series of messages between the Input Generator and the ToE.

So Flinder can understand protocol steps and modify messages between the Input Generator and the ToE, aiming to reveal the typical security-relevant programming bugs. Generic testing algorithms are then used, that can work on the internal representation of parsed messages.

For making testing more efficient, Flinder is capable of looking for different bugs **concurrently** (e.g. by testing different buffers simultaneously). Furthermore, by taking the responses of the ToE into account, Flinder can employ reactive testing to better identify potential security bugs.

Based on the availability of the source code Flinder can be used in black-box or white-box scenarios:

- In the **black-box mode** the ToE is evaluated in its executable form and Flinder supplies the input directly to it and draws conclusions based on successful or

2 For more information about the Flinder tool, see www.flinder.hu.

abnormal reaction (e.g. OS level signals).

- **White-box testing** could be applied if the source code is available. This way Flinder could inject the modified test vectors into the tested functions directly, this way it could achieve a much bigger coverage and Flinder could be involved in the internal (source code level) testing of a product.

4.3 Testing the IFX TSS

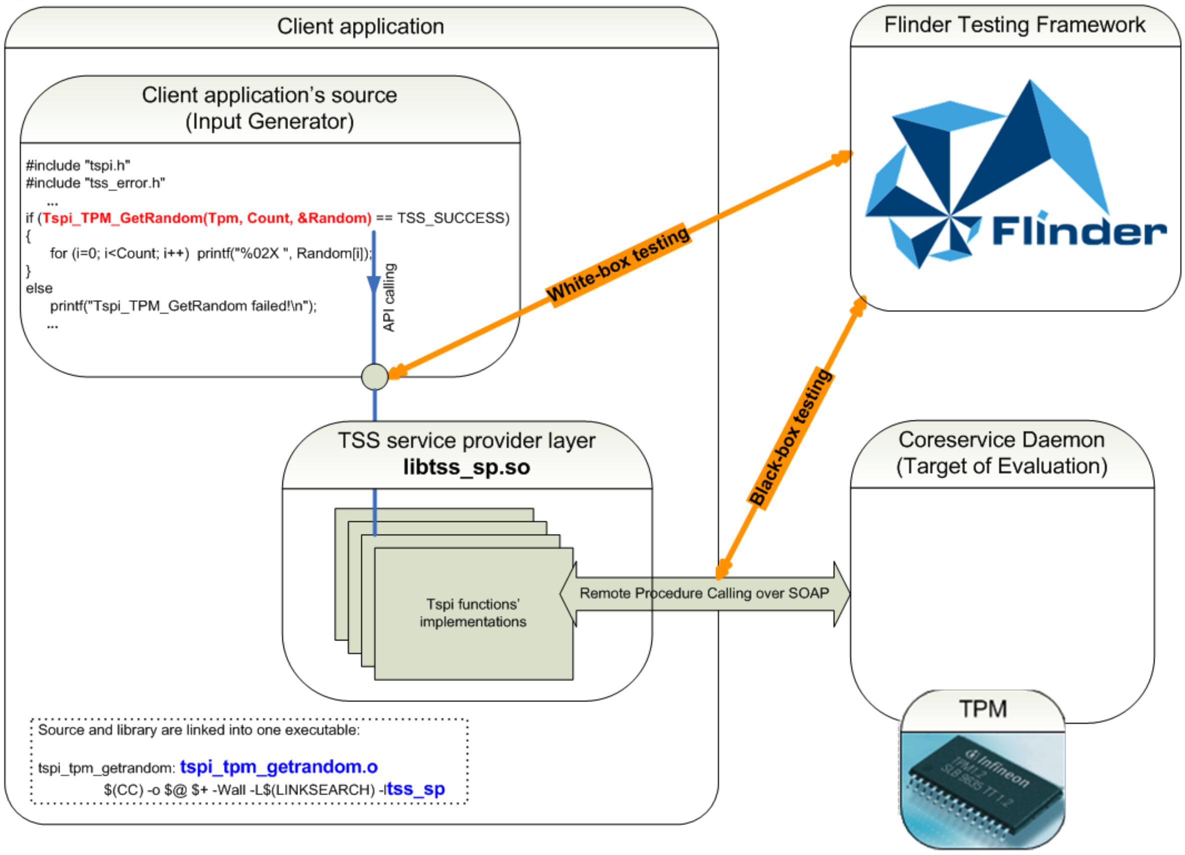
The first target tested with the automated security testing methodology of SWP07a was the Infineon TCG Software Stack (TSS).

For the testing of the IFX TSS BME completed the whole test process introduced previously, i.e. tests were carried out according to the Test Plan resulting in an Internal Test Report, then IFX carried out bugfixing based on support from BME and finally, the corrections were verified by BME resulting in the Public Test Report, which could state that all identified bugs have been corrected.

4.3.1 Test approaches

In order to evaluate the OpenTC Infineon TSS implementation BME carried out automated security testing using the Flinder [FLINDER] tool. This tool was selected after having carried out a comprehensive study in the field of automated security testing utilities. The main properties of Flinder and the generic overview of testing will be omitted from this document, they can be obtained from the Flinder Methodology Overview [FLINDER-METH].

Two venues shall be considered for testing the TCG Software Stack (TSS) implementation:



- The first approach targets the TCG Service Provider Interface (TSPI) and will employ white-box testing techniques for vulnerability assessment. With this method we will be able to evaluate integrity issues of the Service Provider (SP) part of the TSS implementation.
- Other means shall be used for the second approach: black-box testing of the SOAP transport layer. This time, deeper levels of the TSS are scrutinized for potential threats. The SOAP communication link is targeted because it is the interface to the TSS Core Services (TCS) layer implemented in the coreserviced process. This approach will enable to assess the security and interoperability of the Core Service (CS) part of the TSS implementation.

4.3.1.1 White-box testing at API-level via fault injection

White-box testing shall be used to test the TSS implementation at the TSPI level. Of the available interfaces TSPI is the highest level API provided by the TSS for application programming. Systematically investigating the TSPI involves examining every individual interface function looking for typical security-relevant programming bugs. This target shall be reached by executing the following work phases:

1. Identification of TSPI functions with potential risks. Output of this phase: list of function names containing all identified API members.
2. A database of test programs shall be compiled that exercise all functions identified in the first phase.
3. Every test program shall be executed multiple times with a different set of parameters on each run. Test program execution and modification of the test

parameters shall be executed automatically by the Flinder tool. The Flinder tool’s algorithms shall modify the input parameters in a systematic way, with the aim to locate potential weaknesses in the implementation.

Test Program Hooking

In order to control the input parameters by Flinder the source code of the test programs needs to be instrumented. The instrumentation allows Flinder to inject a new set of parameters into the API functions. To accomplish this, additional care needs to be taken by the inserted code to achieve synchronization of the test program and the Flinder testing logic.

The following figures demonstrate a code snippet before and after instrumentation.

```
Tspi_Context_GetTpmObject(Context,&Tpm);
Tspi_GetPolicyObject(Tpm, TSS_POLICY_USAGE, &Policy);
Tspi_Policy_SetSecret(Policy, TSS_SECRET_MODE_PLAIN,
ownerpwdlen, ownerpwd);
```

Figure 2: Code snippet before instrumentation

The target of evaluation in this case is the `Tspi_Policy_SetSecret` function. The parameters `ownerpwdlen`, `ownerpwd` are hooked for modification by Flinder.

```
Tspi_Context_GetTpmObject(Context,&Tpm);
Tspi_GetPolicyObject(Tpm, TSS_POLICY_USAGE, &Policy);
FlinderTypeA a; a.len = ownerpwdlen; a.buf = ownerpwd;
flinderHookA(a);
Tspi_Policy_SetSecret(Policy, TSS_SECRET_MODE_PLAIN,
a.len, (BYTE*)a.buf);
```

Figure 3: Modified code

In this case hooking first involves the creation of a temporary variable holding all function parameters. The `flinderHookA` function is then responsible for the hooking operation. Since it accepts a structure as input parameter the target variables have to be packed before transmission. The modified values can be retrieved from the input structure after the hooking checkpoint is cleared.

Building on the synchronization and data flow mechanisms inserted into the test programs the following test cycle shall be realized by Flinder:

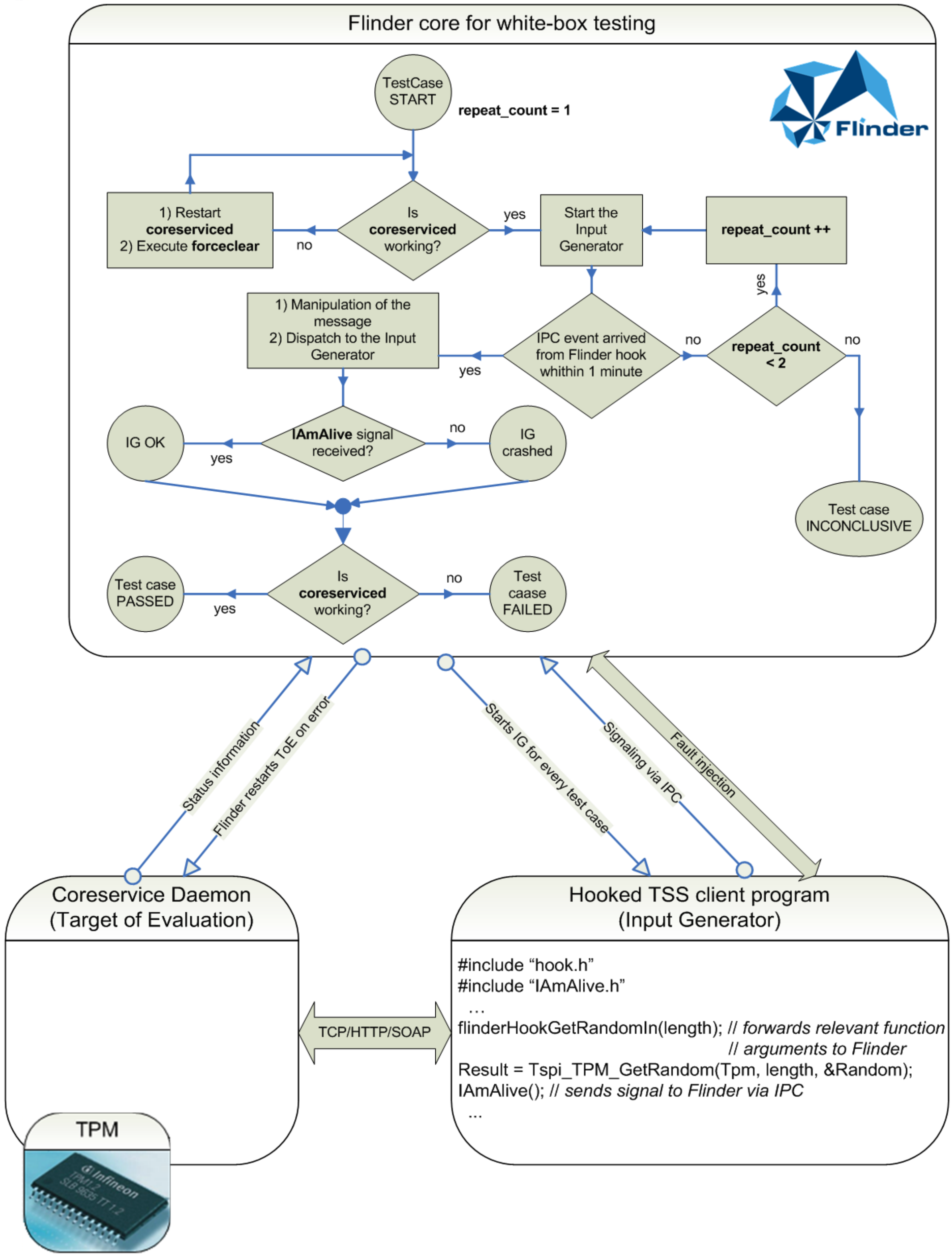


Figure 4: Hooking cycle

The hooking cycle can be described as follows: Flinder starts the Input Generator (IG). The IG runs until the execution flow hits the hooking checkpoint. At the hooking point the IG transfers the input data to Flinder and then waits for reply. Flinder processes the data and sends the test vector back to the IG. In each test case a different test vector is created systematically by Flinder. The IG resumes execution with the modified data. Meanwhile Flinder monitors the execution of `coreserviced` and also of the Input Generator and determines whether they work normally or reached an abnormal state. Flinder terminates the Input Generator, restarts `coreserviced`, sends `forceClear` command to TPM if any is necessary and starts a new cycle.

This procedure shall be executed for every API function identified.

4.3.1.2 Black-box testing at the SOAP connection level

The implementation of the TSS is realized by two communicating processes. Driving the kernel device driver and providing the core service functionality is provided by the `coreserviced` demon server process. Two TSS layers are implemented in this process, the TDDL and the TCS. The `coreserviced` process exposes a programming interface, which clients can access through the SOAP protocol.

The remaining part of the TSS is implemented in the context of the client process. That is only one layer, namely the TSP layer. TSP is built on top of TCS functionality, which can be accessed through a TCS binding proxy inside the client's address space. Internally the binding proxy makes use of the SOAP protocol to access the services of the core service demon in turn.

Not unlike the approach described in the previous section, testing will be performed along similar lines than the hooking cycle. Flinder starts the Input Generator, but now instead of hooking the source code, the SOAP communication is intercepted. A SOAP proxy is inserted into the data stream, which channels data to Flinder. The intercepted data is modified and then routed back to its original destination.

The main advantage of this procedure is that now the implementation of the `coreserviced` is under investigation, and not that of the client process. In this setting malfunctions or crashes of the client process do not mask potential failures in the core service demon.

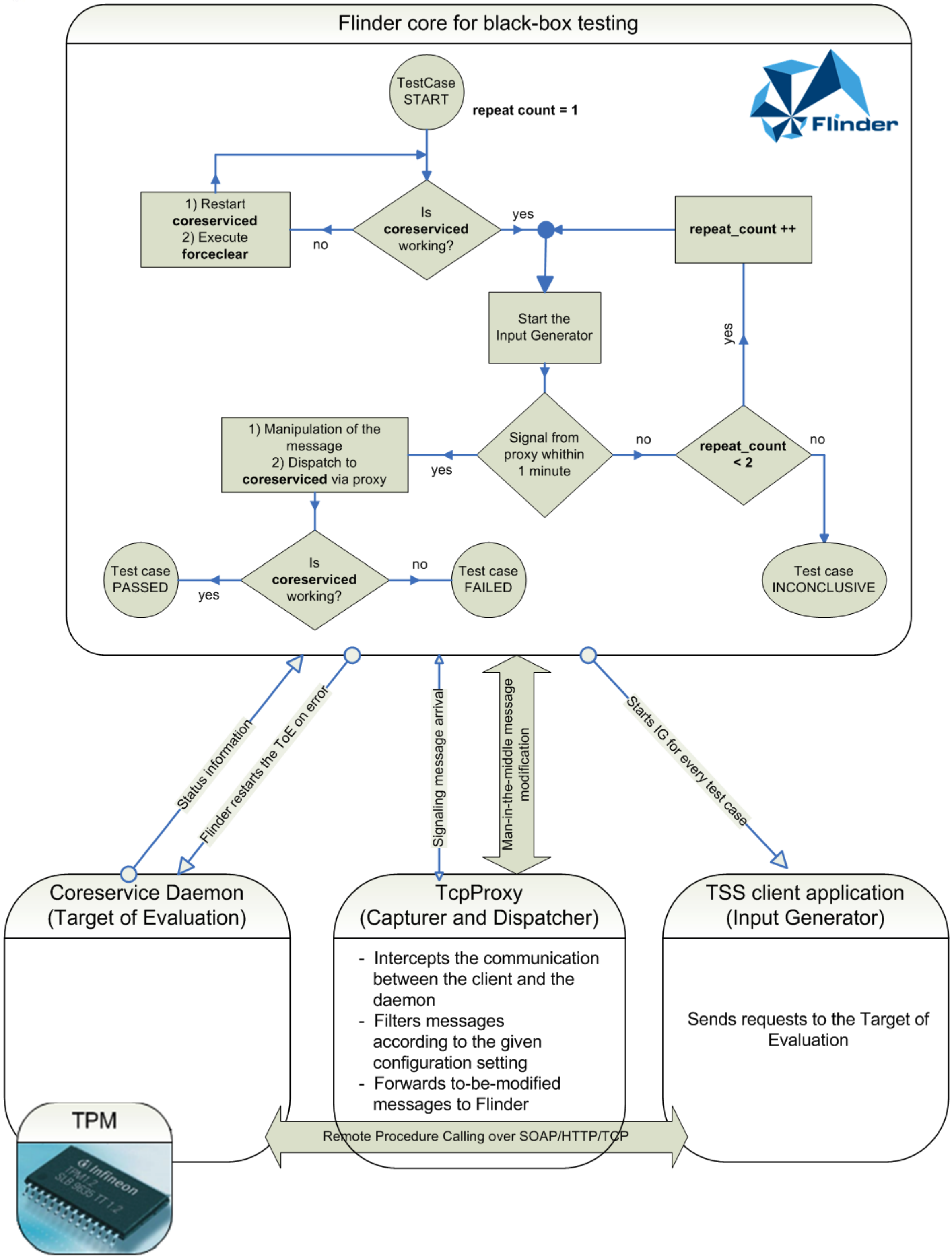


Figure 5: SOAP transport level hooking

4.3.2 Testing Phase

This chapter describes the test cases that were actually executed during the first automated security testing of the OpenTC Infineon TSS implementation. The approach used for the test execution was already introduced in the previous section.

Note: this section reflects the results of the initial security testing activity and thus includes the references to all found security weaknesses. The next section – Regression testing lists the results of the regression testing activity and discusses how the found weaknesses have been eliminated.

4.3.2.1 Test summary

This section gives an overview on the results of the overall testing process. In the following table we have listed all appointed TSPI functions and will give a status indication about the finished testing process. The following categories have been set up in order to simplify the table (the abbreviations will be used throughout the document):

- COMPLETED: All planned test cases were executed successfully, no security weaknesses found.
- PROBLEM 💣: Test case execution revealed security weaknesses, which might have resulted also in incomplete test execution (i.e. ToE could not be reset and restarted automatically).
- NOSOAP: TSPI command did not generate SOAP messages, thus black-box testing was not executed.
- CANCELED: TSPI commands removed from the list of to-be-tested functions according to the phone conference held on January 9, 2007.
- NONCOMP: Test execution could not be completed due to problems in test automation. Detailed description of the problem will be given later.
- NOTIMP: TSPI function returned ‘not implemented’ error code in all evaluated versions of the ToE.

TEST SUMMARY			
Area	Command	Status	
		Black-box	**White-box**
Common Methods (7)	Tspi_SetAttribUint32	NOSOAP	COMPLETED
	Tspi_GetAttribUint32	COMPLETED	COMPLETED
	Tspi_SetAttribData	NOSOAP	COMPLETED
	Tspi_GetAttribData	COMPLETED	COMPLETED
	Tspi_ChangeAuth	PROBLEM M	COMPLETED
	Tspi_GetPolicyObject	NOSOAP	COMPLETED
Context Class Methods (17)	Tspi_Context_Create	NOSOAP	COMPLETED
	Tspi_Context_Close	COMPLETED	COMPLETED
	Tspi_Context_Connect	COMPLETED	COMPLETED
	Tspi_Context_FreeMemory	NOSOAP	COMPLETED
	Tspi_Context_GetDefaultPolicy	NOSOAP	COMPLETED
	Tspi_Context_CreateObject	COMPLETED	PROBLEM M
	Tspi_Context_CloseObject	COMPLETED	COMPLETED
	Tspi_Context_GetCapability	COMPLETED	COMPLETED
	Tspi_Context_GetTPMObject	NOSOAP	COMPLETED
	Tspi_Context_LoadKeyByBlob	COMPLETED	COMPLETED
	Tspi_Context_LoadKeyByUUID	PROBLEM M	PROBLEM M
	Tspi_Context_RegisterKey	NONCOMP(1)	NONCOMP(1)
	Tspi_Context_UnregisterKey	NONCOMP(1)	PROBLEM M
	Tspi_Context_DeleteKeyByUUID	NOTIMP	NOTIMP
	Tspi_Context_GetKeyByUUID	NOTIMP	NOTIMP
	Tspi_Context_GetKeyByPublicInfo	NOTIMP	NOTIMP
	Tspi_Context_GetRegisteredKeysByUUID	NOTIMP	NOTIMP
Policy Class Methods (3)	Tspi_Policy_SetSecret	NOSOAP	COMPLETED
	Tspi_Policy_FlushSecret	NOSOAP	COMPLETED
	Tspi_Policy_AssignToObject	NOSOAP	COMPLETED

TEST SUMMARY			
Area	Command	Status	
		Black-box	White-box
TPM Class Methods (34)	Tspi_TPM_CreateEndorsementKey	NOTIMP	NOTIMP
	Tspi_TPM_GetPubEndorsementKey	COMPLETED	COMPLETED
	Tspi_TPM_TakeOwnership	NONCOMP(2)	NONCOMP(2)
	Tspi_TPM_CollateIdentityRequest	NOTIMP	NOTIMP
	Tspi_TPM_ActivateIdentity	NOTIMP	NOTIMP
	Tspi_TPM_ClearOwner	NONCOMP(2)	NONCOMP(2)
	Tspi_TPM_SetStatus	COMPLETED	COMPLETED
	Tspi_TPM_GetStatus	COMPLETED	COMPLETED
	Tspi_TPM_SelfTestFull	COMPLETED	COMPLETED
	Tspi_TPM_CertifySelfTest	NOTIMP	NOTIMP
	Tspi_TPM_GetTestResult	COMPLETED	COMPLETED
	Tspi_TPM_GetCapability	COMPLETED	COMPLETED
	Tspi_TPM_GetCapabilitySigned	NOTIMP	NOTIMP
	Tspi_TPM_KillMaintenanceFeature	CANCELED	CANCELED
	Tspi_TPM_LoadMaintenancePubKey	CANCELED	CANCELED
	Tspi_TPM_CheckMaintenancePubKey	NOTIMP	NOTIMP
	Tspi_TPM_GetRandom	COMPLETED	COMPLETED
	Tspi_TPM_StirRandom	COMPLETED	COMPLETED
	Tspi_TPM_AuthorizeMigrationTicket	COMPLETED	COMPLETED
	Tspi_TPM_GetEvent	NOTIMP	NOTIMP
	Tspi_TPM_GetEvents	NOTIMP	NOTIMP
	Tspi_TPM_GetEventLog	NOTIMP	NOTIMP
	Tspi_TPM_Quote	COMPLETED	COMPLETED
	Tspi_TPM_PcrExtend	PROBLEM M	COMPLETED
	Tspi_TPM_PcrRead	COMPLETED	COMPLETED
	Tspi_TPM_DirWrite	NOTIMP	NOTIMP
	Tspi_TPM_DirRead	NOTIMP	NOTIMP
	Tspi_TPM_KeyControlOwner	NOTIMP	NOTIMP
	Tspi_TPM_CreateRevocableEndorsementKey	NOTIMP	NOTIMP
	Tspi_TPM_RevokeEndorsementKey	NOTIMP	NOTIMP
	Tspi_TPM_Delegate_AddFamily	CANCELED	CANCELED
	Tspi_TPM_Delegate_GetFamily	CANCELED	CANCELED
	Tspi_TPM_Delegate_CreateDelegation	CANCELED	CANCELED
	Tspi_TPM_Delegate_CacheOwnerDelegation	CANCELED	CANCELED

TEST SUMMARY			
Area	Command	Status	
		Black-box	**White-box**
Key Class Methods (8)	Tspi_Key_LoadKey	COMPLETED	COMPLETED
	Tspi_Key_GetPubKey	COMPLETED	COMPLETED
	Tspi_Key_CertifyKey	NOTIMP	NOTIMP
	Tspi_Key_CreateKey	PROBLEM M	COMPLETED
	Tspi_Key_WrapKey	NOSOAP	COMPLETED
	Tspi_Key_CreateMigrationBlob	COMPLETED	COMPLETED
	Tspi_Key_ConvertMigrationBlob	COMPLETED	COMPLETED
	Tspi_Key_CMKConvertMigration	NOTIMP	NOTIMP
Hash Class Methods (5)	Tspi_Hash_Sign	COMPLETED	COMPLETED
	Tspi_Hash_VerifySignature	NOSOAP	COMPLETED
	Tspi_Hash_SetHashValue	NOSOAP	COMPLETED
	Tspi_Hash_GetHashValue	NOSOAP	COMPLETED
	Tspi_Hash_UpdateHashValue	NOTIMP	NOTIMP
Data Class methods (4)	Tspi_Data_Bind	NOSOAP	COMPLETED
	Tspi_Data_Unbind	COMPLETED	COMPLETED
	Tspi_Data_Seal	PROBLEM M	COMPLETED
	Tspi_Data_Unseal	COMPLETED	COMPLETED
PCR Class Methods (6)	Tspi_PcrComposite_SelectPcrIndex	NOSOAP	COMPLETED
	Tspi_PcrComosite_SetPcrValue	NOSOAP	COMPLETED
	Tspi_PcrComposite_GetPcrValue	NOSOAP	COMPLETED
	Tspi_PcrComposite_SelectPcrIndexEx	NOTIMP	NOTIMP
	Tspi_PcrComposite_SetPcrLocality	NOTIMP	NOTIMP
	Tspi_PcrComposite_GetCompositeHash	NOTIMP	NOTIMP
DER support (2)	Tspi_EncodeDER_TssBlob	NOSOAP	COMPLETED
	Tspi_DecodeBER_TssBlob	NOSOAP	COMPLETED
Non volatile memory (2)	Tspi_NV_WriteValue	COMPLETED	COMPLETED
	Tspi_NV_ReadValue	COMPLETED	COMPLETED

TEST SUMMARY			
Area	Command	Status	
		Black-box	White-box
Direct Autonomous Attestation (7)	Tspi_DAA_IssueSetup	NOTIMP	NOTIMP
	Tspi_DAA_IssueInit	NOTIMP	NOTIMP
	Tspi_DAA_IssueCredential	NOTIMP	NOTIMP
	Tspi_DAA_VerifySignature	NOTIMP	NOTIMP
	Tspi_TPM_DAA_JoinInit	NOTIMP	NOTIMP
	Tspi_TPM_DAA_JoinCreateDaaPubKey	NOTIMP	NOTIMP
	Tspi_TPM_DAA_Sign	NOTIMP	NOTIMP

TEST SUMMARY			
		Status	
		Black-box	White-box
Summary	PROBLEM 💣	5	3
	COMPLETED	28	51
	NONCOMP	4	3
	NOSOAP	20	n/a
	NOTIMP	31	31
	CANCELED	6	6
	Total	94	94

Note: The table above is a summary of the initial testing of the TSS. During the regression testing after the bugfixes of Infineon BME verified that all identified bugs have been corrected.

Statistics

The following table gives a short summary about the ratio of the different categories. Interesting information can be deduced from:

- the ratio of the number of functions in all different groups, giving an insight about the efficiency of the plan;
- the ratio of the number of functions in the groups representing executed tests (i.e. PROBLEM and COMPLETED), giving insight about the ratio of weaknesses in a set of API functions; and
- the ratio of test cases in the different groups, giving insight about the efficiency of Flinder in finding weaknesses.

Category	Ratio of functions in all categories		Ratio of functions among those having had tests		Ratio of executed test cases	
	Black-box	White-box	Black-box	White-box	Black-box	White-box
PROBLEM 💣	4.3%	3.2%	12.1%	5.6%	0.4%	0.2%

COMPLETED	30.9%	54.3%	87.9%	94.4%	99.6%	99.8%
NONCOMP	4.3%	3.2%				
NOSOAP	21.3%	n/a				
NOTIMP	33.0%	33.0%				
CANCELED	6.4%	6.4%				

Table 6: Statistics on test categories

Note on not completed tests

The following group of TSPI functions could not be tested:

(1) : test programs supplied with the ToE were not working, BME efforts to create functional Input Generators did not succeed.

(2) : we could not automate the test execution for these functions, as each test case would have needed manual TPM reset during the boot-up from the BIOS of the PC.

4.3.2.2 Black-box SOAP testing

This section introduces the results of the black-box SOAP testing.

SOAP message testing summary

The table below summaries the results of the black-box SOAP testing. The testing method was elaborated in depth previously.

Although only a relatively small subset of TSPI commands generate SOAP messages, we could successfully find weaknesses with this method.

For the status indication of the table we use the categories already introduced:

- COMPLETED: All planned test cases were executed successfully, no security weaknesses found.
- PROBLEM : Test case execution revealed security weaknesses, which might have resulted also in incomplete test execution (i.e. ToE could not be reset and restarted automatically).
- NONCOMP: Test execution could not be completed due to problems in test automation. Detailed description of the problem will be given later.

SOAP message	Status	Tested software version	Test cases executed	Test cases failed
AuthorizeMigrationKey	COMPLETED	2007.01.12.	1039	0
ChangeAuth	PROBLEM 💣	2007.01.12.	1121	2
ConvertMigrationBlob	COMPLETED	2007.01.12.	1055	0
CreateMigrationBlob	COMPLETED	2007.01.12.	2041	0
CreateWrapKey	COMPLETED	2007.01.12.	1074	0
Extend	PROBLEM 💣	2007.01.12.	1040	8
FlushSpecific	COMPLETED	2007.01.12.	2048	0
GetCapability	COMPLETED	2007.01.12.	1047	0
GetCapabilityTpm	COMPLETED	2007.01.12.	1045	0
GetPubKey	COMPLETED	2007.01.12.	1081	0
GetRandom	COMPLETED	2007.01.12.	1024	0
GetRegisteredKeyBlob	PROBLEM 💣	2007.01.12.	178	49
GetTestResult	COMPLETED	2007.01.12.	1024	0
LoadKey2ByBlob	COMPLETED	2007.01.12.	1038	0
NV_ReadValue	COMPLETED	2007.01.12.	2204	0
NV_ReadValueAuth	COMPLETED	2007.01.12.	3072	0
NV_WriteValue	COMPLETED	2007.01.12.	2067	0
NV_WriteValueAuth	COMPLETED	2007.01.12.	2067	0
OIAP	COMPLETED	2007.01.12.	1024	0
OSAP	PROBLEM 💣	2007.01.12.	1320	190
OwnerClear	NONCOMP (2)	2007.01.12.	0	0
OwnerSetDisableState	COMPLETED	2007.01.12.	2048	0
PcrRead	COMPLETED	2007.01.12.	1024	0
Quote	COMPLETED	2007.01.12.	2056	0
ReadPubEk	COMPLETED	2007.01.12.	19	0
Seal	COMPLETED	2007.01.12.	59	0
SelfTestFull	COMPLETED	2007.01.12.	1024	0
SetCapability	COMPLETED	2007.01.12.	1068	0
StirRandom	COMPLETED	2007.01.12.	20	0
TakeOwnership	NONCOMP (2)	2007.01.12.	0	0
UnBind	COMPLETED	2007.01.12.	1097	0
UnSeal	COMPLETED	2007.01.12.	1039	0
Sign	COMPLETED	2007.01.12.	1043	0
Summary			**38106**	**249**

Table 7: SOAP message testing summary

Note on not completed tests

The following group of TSPI functions could not be tested:

(2) : we could not automate the test execution for these functions, as each test case would have needed manual TPM reset during the boot-up from the BIOS of the

Security problems identified during black-box testing

This section lists the weaknesses found during black-box testing. It has to be emphasized that the target of the security testing was to find weaknesses, thus this document will give relatively small emphasize on the correct implementation. Thus, although the greater part of this document deals with problems, the Target of Evaluation behaved correctly in the vast majority of tests.

ID	OPENTC-RACK51-54-20070328_BB-G008 and OPENTC-RACK51-54-20070328_BB-G009
Name	`OSAP` Integer Overflow
Affected software version	2007.01.12 and 2007.03.16
Description	`coreserviced` shutdown upon receipt of Flinder-modified SOAP message

ID	OPENTC-RACK51-54-20070328_BB-G056
Name	`ChangeAuth` Integer Overflow
Affected software version	2007.01.12 and 2007.03.16
Description	`coreserviced` shutdown upon receipt of Flinder-modified SOAP message

ID	OPENTC-RACK51-54-20070328_BB-G109
Name	`Extend` Buffer Overflow
Affected software version	2007.01.12 and 2007.03.16
Description	`coreserviced` would not respond further requests upon receipt of Flinder-modified SOAP message

ID	OPENTC-RACK51-54-20070328_BB-G136
Name	`GetRegisteredKeyBlob` Integer Overflow
Affected software version	2007.01.12
Description	`coreserviced` shutdown upon receipt of Flinder-modified SOAP message

ID	OPENTC-RACK51-54-20070328_BB-G137
Name	`GetRegisteredKeyBlob` Buffer Overflow
Affected software version	2007.01.12
Description	`coreserviced` shutdown upon receipt of Flinder-modified SOAP message

4.3.2.3 White-box testing

This section introduces the results of the fault-injection-based white-box testing.

White-box testing summary

The table below summaries the results of the white-box testing. The testing method was elaborated in depth previously.

For the status indication of the table we use the categories introduced previously:

- COMPLETED: All planned test cases were executed successfully, no security weaknesses found.
- PROBLEM : Test case execution revealed security weaknesses, which might have resulted also in incomplete test execution (i.e. ToE could not be reset and restarted automatically).
- NONCOMP: Test execution could not be completed due to problems in test automation. Detailed description of the problem will be given later.

Command	Status	Tested software version	Test cases executed	Test cases failed
Tspi_SetAttribUint32	COMPLETED	2007.01.12.	4096	0
Tspi_GetAttribUint32	COMPLETED	2007.01.12.	3072	0
Tspi_SetAttribData	COMPLETED	2007.01.12.	3087	0
Tspi_GetAttribData	COMPLETED	2007.01.12.	3072	0
Tspi_ChangeAuth	COMPLETED	2007.01.12.	3072	0
Tspi_GetPolicyObject	COMPLETED	2007.01.12.	1024	0
Tspi_Context_Create	COMPLETED	2007.01.12.	0	0
Tspi_Context_Close	COMPLETED	2007.01.12.	1024	0
Tspi_Context_Connect	COMPLETED	2007.01.12.	1042	0
Tspi_Context_FreeMemory	COMPLETED	2007.01.12.	1040	0
Tspi_Context_GetDefaultPolicy	COMPLETED	2007.01.12.	1024	0
Tspi_Context_CreateObject	PROBLEM	2007.01.12.	70	70
Tspi_Context_CloseObject	COMPLETED	2007.01.12.	1024	0
Tspi_Context_GetCapability	COMPLETED	2007.01.12.	1047	0
Tspi_Context_GetTPMObject	COMPLETED	2007.01.12.	1024	0
Tspi_Context_LoadKeyByBlob	COMPLETED	2007.01.12.	1038	0
Tspi_Context_LoadKeyByUUID	PROBLEM	2007.01.12.	112	83
Tspi_Context_RegisterKey	NONCOMP(1)	2007.01.12.	0	0
Tspi_Context_UnregisterKey	PROBLEM (1)	2007.01.12.	496	1
Tspi_Policy_SetSecret	COMPLETED	2007.01.12.	1043	0
Tspi_Policy_FlushSecret	COMPLETED	2007.01.12.	1024	0
Tspi_Policy_AssignToObject	COMPLETED	2007.01.12.	2048	0
Tspi_TPM_GetPubEndorsementKey	COMPLETED	2007.03.16.	3370	0

Tspi_TPM_TakeOwnership	NONCOMP(2)		0	0
Tspi_TPM_ClearOwner	NONCOMP(2)		0	0
Tspi_TPM_SetStatus	COMPLETED	2007.01.12.	2048	0
Tspi_TPM_GetStatus	COMPLETED	2007.01.12.	1024	0
Tspi_TPM_SelfTestFull	COMPLETED	2007.01.12.	1024	0
Tspi_TPM_GetTestResult	COMPLETED	2007.01.12.	1024	0
Tspi_TPM_GetCapability	COMPLETED	2007.01.12.	3072	0
Tspi_TPM_GetRandom	COMPLETED	2007.01.12.	1024	0
Tspi_TPM_StirRandom	COMPLETED	2007.01.12.	15	0
Tspi_TPM_AuthorizeMigrationTicket	COMPLETED	2007.01.12.	2048	0
Tspi_TPM_Quote	COMPLETED	2007.01.12.	4394	0
Tspi_TPM_PcrExtend	COMPLETED	2007.01.12.	3393	0
Tspi_TPM_PcrRead	COMPLETED	2007.01.12.	1024	0
Tspi_Key_LoadKey	COMPLETED	2007.01.12.	2048	0
Tspi_Key_UnloadKey	COMPLETED	2007.01.12.	1024	0
Tspi_Key_GetPubKey	COMPLETED	2007.01.12.	1024	0
Tspi_Key_CreateKey	COMPLETED	2007.01.12.	3072	0
Tspi_Key_WrapKey	COMPLETED	2007.01.12.	3072	0
Tspi_Key_CreateMigrationBlob	COMPLETED	2007.01.12.	2063	0
Tspi_Key_ConvertMigrationBlob	COMPLETED	2007.01.12.	2079	0
Tspi_Hash_Sign	COMPLETED	2007.03.16	2048	0
Tspi_Hash_VerifySignature	COMPLETED	2007.03.16	1039	0
Tspi_Hash_SetHashValue	COMPLETED	2007.03.16	19	0
Tspi_Hash_GetHashValue	COMPLETED	2007.03.16	1024	0
Tspi_Data_Bind	COMPLETED	2007.01.12.	2067	0
Tspi_Data_Unbind	COMPLETED	2007.01.12.	2048	0
Tspi_Data_Seal	COMPLETED	2007.01.12.	3089	0
Tspi_Data_Unseal	COMPLETED	2007.01.12.	2048	0
Tspi_PcrComposite_SelectPcrIndex	COMPLETED	2007.01.12.	2048	0
Tspi_PcrComposite_SetPcrValue	COMPLETED	2007.01.12.	1043	0
Tspi_PcrComposite_GetPcrValue	COMPLETED	2007.01.12.	2048	0
Tspi_NV_WriteValue	COMPLETED	2007.01.12.	2067	0
Tspi_NV_ReadValue	COMPLETED	2007.01.12.	3072	0
Tspi_NV_DefineSpace	COMPLETED	2007.01.12.	3072	0
Tspi_DecodeBER_TssBlob	COMPLETED	2007.03.16.	1039	0
Tspi_EncodeDER_TssBlob	COMPLETED	2007.03.16.	1039	0
Summary			**97131**	**154**

Table ***8:*** White-box testing summary

Note on not completed tests

The following group of TSPI functions could not be tested:

(1) : test programs supplied with the ToE were not working, BME efforts to create functional Input Generators did not succeed.

(2) : we could not automate the test execution for these functions, as each test case would have needed manual TPM reset during the boot-up from the BIOS of the PC.

Security problems identified during white-box testing

This section lists the weaknesses found during white-box testing.

ID	OPENTC-RACK51-54-20070328_WB-G034
Name	`Tspi_Context_UnregisterKey` Integer Overflow
Affected software version	2007.01.12
Description	`coreserviced` exited after having issued this API function

ID	OPENTC-RACK51-54-20070328_WB-G127
Name	`Tspi_Context_LoadKeyByUUID` Integer Overflow
Affected software version	2007.01.12
Description	`coreserviced` exited after having issued this API function

ID	OPENTC-RACK51-54-20070328_WB-G164 and OPENTC-RACK51-54-20070328_WB-G165
Name	`Tspi_Context_CreateObject` Integer Overflow
Affected software version	2007.01.12
Description	`coreserviced` exited after having issued this API function

4.3.3 Regression testing

After having delivered the Internal Test Report to Infineon, Infineon carried out bugfixing on the Target of Evaluation in cooperation with BME. Several intermediate versions of the ToE were evaluated during this period, and in the end BME could verify that the last evaluated version (of 2007.07.25) did not contain any of the found weaknesses. By correcting all found issues, Infineon produced a TSS implementation that successfully passed the requirements set forth in this document verified with the help of the automated security testing tool Flinder.

In the following sections descriptions will be given on how each found weakness was addressed.

4.3.3.1 Security problems identified during black-box testing

This section describes how the issues found via black-box testing were addressed.

ID	OPENTC-RACK51-54-20070328_BB-G008 and OPENTC-RACK51-54-20070328_BB-G009
Name	`OSAP` Integer Overflow
Affected software version	2007.01.12 and 2007.03.16
Corrected software version	n/a (verified to be a false positive)
Method of correction	The weakness was due to a debug-mode assert of the ToE. Release mode versions of the ToE correctly handled such malformed messages and return with the relevant TSS error message and error status. Note: always use the release version of the ToE in a production environment in order to ensure that this weakness cannot be exploited.

ID	OPENTC-RACK51-54-20070328_BB-G056
Name	`ChangeAuth` Integer Overflow
Affected software version	2007.01.12 and 2007.03.16
Corrected software version	n/a (verified to be a false positive)
Method of correction	The weakness was due to a debug-mode assert of the ToE. Release mode versions of the ToE correctly handled such malformed messages and returned with the relevant TSS error message and error status. Note: always use the release version of the ToE in a production environment in order to ensure that this weakness cannot be exploited.

ID	OPENTC-RACK51-54-20070328_BB-G109
Name	`Extend` Buffer Overflow
Affected software version	2007.01.12 and 2007.03.16
Corrected software version	2007.07.25
Method of correction	Infineon implemented adequate length checking on the respective parameter of the Extend message, which correctly handled malformed messages and returned with the relevant TSS error message and error status. Note: always use the 2007.07.25 or later versions of the ToE in a production environment in order to ensure that this weakness cannot be exploited.

ID	OPENTC-RACK51-54-20070328_BB-G136
Name	`GetRegisteredKeyBlob` Integer Overflow

Affected software version	2007.01.12
Corrected software version	2007.03.16
Method of correction	This weakness was only present in the 2007.01.12 version of the TSS. Later versions were not affected. Note: always use the 2007.03.16 or later versions of the ToE in a production environment in order to ensure that this weakness cannot be exploited.

ID	OPENTC-RACK51-54-20070328_BB-G137
Name	`GetRegisteredKeyBlob` Buffer Overflow
Affected software version	2007.01.12
Corrected software version	2007.03.16
Method of correction	This weakness was only present in the 2007.01.12 version of the TSS. Later versions were not affected. Note: always use the 2007.03.16 or later versions of the ToE in a production environment in order to ensure that this weakness cannot be exploited.

4.3.3.2 Security problems identified during white-box testing

This section describes how the issues found via white-box testing were addressed.

ID	OPENTC-RACK51-54-20070328_WB-G034
Name	`Tspi_Context_UnregisterKey` Integer Overflow
Affected software version	2007.01.12
Corrected software version	2007.03.16
Method of correction	This weakness was only present in the 2007.01.12 version of the TSS. Later versions were not affected. Note: always use the 2007.03.16 or later versions of the ToE in a production environment in order to ensure that this weakness cannot be exploited.

ID	OPENTC-RACK51-54-20070328_WB-G127
Name	`Tspi_Context_LoadKeyByUUID` Integer Overflow
Affected software version	2007.01.12
Corrected software version	2007.03.16
Method of correction	This weakness was only present in the 2007.01.12 version of the TSS. Later versions were not affected. Note: always use the 2007.03.16 or later versions of the ToE in a production environment in order to ensure that this weakness cannot be exploited.

ID	OPENTC-RACK51-54-20070328_WB-G164 and OPENTC-RACK51-54-20070328_WB-G165
Name	`Tspi_Context_CreateObject` Integer Overflow
Affected software version	2007.01.12
Corrected software version	2007.03.16
Method of correction	This weakness was only present in the 2007.01.12 version of the TSS. Later versions were not affected. Note: always use the 2007.03.16 or later versions of the ToE in a production environment in order to ensure that this weakness cannot be exploited.

4.4 Testing of XEN

In order to evaluate the XEN hypervisor, BME will carry out automated security testing using the Flinder [FLINDER] tool. This tool was selected after having carried out a comprehensive study in the field of automated security testing utilities. The main properties of Flinder and the generic overview of testing will be omitted from this document; they can be obtained from the Flinder Methodology Overview [9].

Based on the relevance of XEN to the OpenTC project and on the most viable scenarios, BME put the following question at the center of the testing process: can a compromized compartment influence another, not compromized compartment, i.e. if an attacker can gain root access in a broken domain, can he carry out operations, which would adversely affect domains, to which he should not have access to.

4.4.1 Test approach

The testing approach targets hypercalls, which were selected as the most security-critical in the XEN architecture:

- `do_mmu_update`
- `do_grant_table_op`
- `do_memory_op`
- `do_domctl`
- `do_page_fault`

BME will employ black-box testing, which will enable us to assess the security and interoperability of the hypercalls' implementations.

As hypercall calling mechanisms were examined we found that there is a global table of hypercalls in every domain's kernel, which can be used to access the hypervisor but that are only accessible by kernel modules. Thus there is an interface established in the `/proc` file system which is accessible under `/proc/xen/privcmd` file; this is a special file and is not stored anywhere on disk but the file handling functions such as open, read, close are able to be overridden by custom functions to implement special activities through standard file handling calls. In case of this pseudo-file the ioctl functions where taken to serve as the interface to access the kernel module's functions which implements this file in the /proc file system.

User space applications use this interface to access all the functionality of the hypervisor because they cannot directly call those functions accessible from kernel code. There are libraries such as libxenctrl which hide these difficulties from application programmers but we will use the raw ioctl interface of privcmd in order to directly manipulate the hypercalls input and prevent the situation when malformed input could get rejected from a user space library, and with high probability this would be the case in real world attacks.

We examined the access control of the interface to hypercalls and it turned out that only root access is defined to the privcmd file by default, and on the hypervisor's side some functions check whether a domain is in privileged mode before executing critical operations.

This scenario is completely compatible with our objective: it is to be evaluated, whether root access from a non-privileged domain could influence other domains. Since only the resources of the compromised virtual machine should be affected, XEN should not be used for attacking the physical machine or other virtual machines. In this case XEN has the highest responsibility to prohibit further damage on other domains.

These considerations led us to focus on this case of attack, so the automated testing of the XEN hypervisor will be carried out in that environment – with root privileges on a guest domain.

4.5 On-going work and future directions

As of the date of this report, BME is actively working on the automated testing of the XEN hypervisor (see previous section). It is planned to be finished around March 2008. The results will be integrated with that of CEA and TUS (who are about to finish XEN testing) and a combined report will be given to the developers of XEN.

After the testing of XEN, BME plans to evaluate the other hypervisor developed in this project, namely L4. However, other software components might be also selected based upon the agreement within WP7 and the project management.

5 Static analysis of targets using AI

5.1 Overview

Static analysis is the preferred technique for ensuring that critical components are correct and safe. The most promising static analysis technique currently is abstract interpretation, that has found numerous applications and that is now built into many static analysis tools, such as the Coverity and Polyspace analysers.

Since the beginning of the project, it was decided to analyse the targets using three directions:

1. The first one makes use of existing stable commercial tools: this enables to understand what state-of-the-art tools can achieve (namely what categories of bugs can be tackled) and with what precision. After a survey of such tools, made during year 1 by TUS, it was decided to buy and use the Coverity Prevent analyser.
2. The second one aims at building a next generation static analyser, which integrates the most advanced (and feasible) techniques from AI, with the objective to build an even preciser static analyser, that is open to other static analysis techniques (essentially Hoare Logic). The Frama-C framework was developed by CEA providing an experimental tool capable of analysing ANSI C code as well as gcc specifics for Intel x86 32, PAE and 64 bits architectures. Whilst developing Frama-C, we applied it to the same targets as done with the other tools of WP07.
3. Most OS targets are written in C, which is well suited to the existing and under-development tools, but some components (such as L4/Fiasco) are written in C++, for which much less research has been done and even less tools are ready. In order to analyse C++, two research streams have been devised, analogous to the two previous ones, namely:
    - Use **Coverity Prevent** to analyse the C/C++ code: this will be done during year 3 by TUS.
    - Research how **Frama-C** can be adapted to analyse C++ code as well: natively, Frama-C does not support C++, therefore it was decided to analyse C++ code by parsing C++ code and translating it into C, that can be “handed over” to the C analyser. A reasonable subset of C++ was used for this extension, covering Pistachio but not L4/Fiasco yet. The translation scheme may sound simple, but brings up many new problems, that are addressed here and solutions proposed. Some of this research is described in this report. Portions of code of Fiasco will be analysed during year 3.

During year 2, both tools have been applied to XEN, which is reported here. The analysis of this target will terminate in year 3, where results on the V&V of XEN will be unified.

As the reader will see in this section, abstract interpretation is capable to find certain kinds of low-level errors, because the domains used to model variables are rather simple: integer intervals with some modulo, union of intervals, polyhedra, octogons, etc. Therefore, Hoare Logic is still necessary to express more complex properties of the C code, by means of assertions, invariants, pre- and post-conditions, etc.

During year 2 CEA has developed ACSL (standing for ANSI C Specification Language), for this purpose. This has been done within RNTL project CAT [10], together with other partners. In OpenTC we will implement this specification language in Frama-C, as well as its C++ version in the C++ prototype. In appendix 1, the reader will find an introduction to ACSL. The ACSL language definition will soon be publicly released.

5.2 Enhancements and support of Frama-C

The year 2007 was spent improving efficiency of the value analysis with respect to the time and memory it requires for the analysis of programs of a respectable size.

5.3.1 Context

The value analysis computes "states" corresponding to each control control point of the analysed program. A "state" is a map from memory locations to values, and in a non-toy language such as C, a memory location can be a field in a struct type, a cell in an array, a scalar variable of one of several base types of different sizes, or even a combination of the above (an array of pointers to structs whose fields are arrays of integers).

States easily take up a lot of space to represent. Although the whole state corresponding to any given control point must be kept in memory, in practice, many of the states that are computed map many memory locations to the same values.

For instance, the respective states corresponding to the controls points just before and just after the statement "x = y + 1;" are identical for every memory location except x.

If the right data structure is chosen to represent states, these states have a chance to share these bindings, and thus the quantity of memory needed to represent the states corresponding to all the control points in the program has a chance to be much less than the product of the quantity of memory needed to represent one state by the number of control points in the analysed program.

The natural choice is to use persistent data structures, so that no in-place modification of the states interfere with sharing. One can think for instance of binary trees where each leaf contains a binding. For the example "x = y + 1;" above, much of the subtrees (in fact, all the subtrees that do not contains variable "x") from the state before the assignment can be re-used to construct the state after the assignment.

Functional programmers worth their salt know how to make good use of sharing. This usually means two things:

* when writing a function that takes in argument a binary tree and returns a transformed version of that tree, the tree returned by the function should share as much as possible of its nodes with the argument.

* when writing a function that takes as argument two trees in order to make a compositional computation of them, if the trees passed to the function happen to share some of their nodes, this

fact should be recognized by the function and the sub-trees should not be explored at all. In addition, if the function returns a tree built from the two arguments, this tree should share with them the nodes that they have in common.

The above is common practice, and the value analysis as it was implemented at the beginning of 2007 followed these principles. Still, performance was not good even for just-slightly-bigger-than-average programs. The memory necessary to analyse a program with big arrays of structures of arrays could go above the symbolic barrier of 4Gb that a single process can address on a 32-bit machine. Needless to say, having to manipulate structures that occupied that much space, the analysis was slow too, so not only the only answer on a big program might be "Out of memory", but this answer would be obtained only after tens of hours of computations.

5.3.2 Discovery

Although this document may make it appear as if it was clear that the problem was in imperfect sharing in the representation of states, it wasn't at the time. At the time, it appeared like perhaps such programs really required that much memory to analyze. Or that states should not be memorized for all control points (however, it was a hard decision to go in that direction, because this memorization is necessary for later reuse of the results of the value analysis by other analyses, and this is intended to be its distinguishing point).

The problem appears when a large number of states s1..sn, which share a lot of nodes, are created (maybe by application of functions f1..fn to some initial state s0), and a function g is then applied to each of them independently. Although sk and sk+1 share a lot of nodes, g(sk) and g(sk+1) do not, because they are built independently by two different applications of g. The only sharing that can be implemented by g is between its argument and its result. Therefore each time the application g(sk+1) needs for building its result a node that is not present in sk+1, it needs to allocate a new one, even if most of the time an identical node has already been built by the application g(sk)

In the value analysis, this exact situation was taking place, with the functions f1..fn being the transition functions between control points in the analyzed code, and the g function being the recording function that saves the results of the analysis for later use by other analyses

In order to obtain better sharing between states in this case, the only way is to rediscover it artificially. That is, for each node that function g is about to allocate, the function must check if an identical node has already been created before (by another call to g or by another function altogether) and reuse it if it exists. If this process is systematic enough, it is possible to obtain the "maximal sharing" property (if two nodes are identical, then they are physically the same node in memory), which allows to decide the equality of arbitrarily big trees in constant time (they are identical if and only if they are at the same address). This technique is called hash-consing. It is in particular instrumental in making BDDs (Binary Decision Trees) as powerful as they are. Although we didn't find any sign of documented use in the implementation of abstract interpretation analyses.

By a lucky coincidence, Ocaml, the language in which the value analysis is implemented, had been providing for a relatively short time the (rather uncommon) construction blocks necessary for implementing hash-consing, weak pointers. Built on weak pointers, Ocaml provided as well the data structure to memorize all the nodes that have already been created before, and, when creating a new one, to find quickly, if an identical node already exists in the table. This data structure is called a weak hash table.

Using the features newly provided by Ocaml, the experiment was made to switch to hash-consing for the construction of states. The switch was not a small task. As was just said, hash-consing works best when any new node that is created is guaranteed to be different from all already existing nodes. There is an overhead for looking up the weak hash table for an identical node at each attempted creation, but this overhead can be kept at a minimum as long as equality between existing trees can be checked in constant time -- that is, as long as the invariant of maximal sharing holds. Therefore, when switching to hash consing, it is vital to make sure that every new node creation now goes through the weak hash table lookup. Besides, there is also the matter of providing a good hash function for trees, so that the lookup can be made efficiently. Since the weak hash table is used all the time, performances degrade very quickly if the hash function for trees is not perfect.

It revealed that hash consing worked! Big programs were using less memory to analyze. All was well.

5.3.3 A new hash-consing library

The size of programs that could be analyzed using hash consing was more than double the size of programs that could be analyzed without it, but the value analyzer still had a tendency to allocate memory at a steady pace and end up using in excess of 2Gb of memory when it was done. The culprit was found to be Ocaml's library for weak hash tables. This implementation of weak hash tables has quite a large overhead, which was thought to be the main problem. This lead to implementing another library for weak hash tables on top of the weak pointers provided by Ocaml. In time, after more experiments, it became clear that the problem with Ocaml's weak hash tables libraries was not so much the high overhead but its tendency to grow the same way a normal hash table would. In Ocaml's implementation, after a fixed number of elements have been inserted into the table, the table is automatically resized, because it is assumed to be full. This is indeed reasonable for a normal hash table, but the particularity of a weak hash table is precisely that it empties itself silently, and that therefore the number of elements inside is not necessarily the number of elements that have been put in. When a weak hash table using this algorithm is used for hash consing, it always grows indefinitely, regardless of the fact that the quantity of live data inside it remains bounded. So the re-implementation of a weak hash table library appeared to be justified once the problem was fully understood, although it was started for the wrong reasons.

Using the newly developed weak hash table library, the same programs that used to barely fit into 2Gb previously can now be analysed within 500Mb of memory.

5.3 Research on the static analysis of C++ code

Although this was not planed at the start of OpenTC, some experiments have been conducted on the feasibility of the analysis of C++ code within the Frama-C framework. Namely, some of the target code for the project is written in C++, in particular the Fiasco micro-kernel, so that the ability to handle C++ code is very relevant in the context of OpenTC. While the development is still at the prototype stage, the results (presented below) so far look very promising. We must mention however, that the first experiments (see section 5.3) did not address Fiasco, but another micro-kernel of the L4 family, Pistachio. The main rationale for this choice is that Pistachio's code is simpler, in the sense that it uses fewer high-level C++ constructs[3], so that a smaller subset of C++ needed to be supported by the first version of the C++ plug-in of Frama-C in order to analyse Pistachio than with Fiasco. Mainly, the plug-in performs a translation from C++ to C, or more exactly to the Frama-C internal representation of a C file. It is then possible to use the various analyses performed by Frama-C as usual.
The remainder of this section is structured as follows. First, we give an overview of the existing analysis tools that target C++. Then, we present the various available C++ front-ends, as designing a C++ parser from scratch was way beyond the scope of this experiment and we describe the main steps of the transformation of a C ++ program into Frama-C internal structures. In section 5.3, we list the main C++ features that are currently supported by the plug-in. Similarly we detail the C++ specific extensions that we have made to the ACSL annotation language in section 5.3. Last, section 5.3 reports on the first analyses that have been conducted with the plug-in on some of the Pistachio's system calls.

5.5.1 Background

While there exists a certain number of static analysis tools targeting C programs, only a few tools are available for C++. As emphasized by Bjarne Stroustrup [StroustrupHOPL2007], this is mainly due to the complexity of the language's grammar, hence to the difficulty of parsing C++ programs. Among the tools that can grasp C++ code, we can cite in particular Coverity (http://www.coverity.com/) and KlocWork (http://www.klocwork.com). They are mainly aimed at detecting potential run-time exceptions (invalid pointer, out-of-bound access in an array, etc.), and are meant to be quite fast, at the expense of the precision of the results: they tend to report a lot of false alarms and to ignore some kinds of errors. In other words, these

3 Namely, Pistachio does not use inheritance.

tools, which are representative of most of the existing static analysers, tend to concentrate on the search of bugs corresponding to particular patterns, rather than attempting to validate the absence of run-time error. They are useful for debugging, (especially since they are reasonably fast) but can not really be trusted in the context of the higher levels of a Common Criteria certification (EAL 6 or 7). The same remark applies to Oink (http://www.cubewano.org/oink/), which uses data-flow analysis to check for format string vulnerabilities. The main target for this class of issues is of course the functions that operates on data coming from some untrusted source in the network. While the oink project is still in a quite early stage of development, its longer-term goal seems to be able to address the Mozilla code base.

Last, Polyspace Verifier (http://www.mathworks.com/products/polyspace/index.html?s_cid=psr_prod) is a very mature tool, which is based on abstract interpretation and for each instruction of the program reports if it certainly leads to an error, may lead to an error, will never cause a run-time error, or is unreachable. On the contrary to the previous tools, Polyspace Verifier is sound, in the sense that any it never misses an alarm. On the other hand, it is not complete: it may report spurious alarms that do not occur in practice and that are an artefact of the abstractions that are done to ensure the termination of the analysis (see [cuoq07] for more information on abstract interpretation). The main difference between Polyspace and Frama-C relies in the fact that Polyspace does not support an annotation language as large as ACSL, so that it is difficult to use it to verify user-defined properties rather than the absence of run-time errors.

Another important aspect of the experiment was the nature of the code that had to be analysed. As shown by the analysis of XEN source (see next section), OS programming has many characteristics that make their analysis quite difficult for automated tools. In particular, it must often perform some very low-level operations on the memory of the system, which tend to break the abstract representation of the memory that is used by the tools. Nevertheless, some projects are currently attempting to formally prove some properties of low-level system programs. Among them, we can cite the Verisoft (http://www.verisoft.de/), a German project, whose target is an home-made micro-kernel and an OS built on top of it. Given their relatively small size, L4-based micro-kernel are better suited for formal verification than monolithic kernel such as Linux. With respect to Fiasco, the VFiasco project [HohmutTR2003] proposes to use a "safe" subset of C++, called SafeC++, for which they attempt to provide a formal semantics. A by-product of the project that is relevant for the analysis of C++ in Frama-C is the release of a library to represent and manipulate C++ expressions in Ocaml, called Olmar (http://www.cs.ru.nl/~tews/olmar/). On the Pistachio side, NICTA has initiated a formalization [ElphinstoneHTOS2007] of the L4 API in the Isabelle proof assistant. At the same time, they intend to provide a reference implementation written in the Haskell programming language, which will be verified against the formal model [TuchPOPL2007]. However, they do not seem to take the current C++ implementation as a target for the verification process.

5.5.2 A C++ Front-end for Frama-C

As said above, the C++ grammar is very complicated, and writing a parser from scratch would have been far beyond the goals of the project. We have thus examined the existing C++ parsers, to see how they might be incorporated in the Frama-C toolset. The most complete C++ front-end for now is the one commercialized by the Edison Development Group (http://www.edg.com/index.php?location=c_frontend). It claims to be the only front-end fully compliant with the ISO C++ standard. In addition

it supports most of the features (and bugs[4]) of the major C++ compiler, and in particular of GCC and Visual C++. However, it is very expensive, especially in the context of a case study, and it is unclear if it could easily be extended to cover the annotation language of Frama-C.
Another possibility would have been to use GCC's internal representation. These internal data-structures have been namely reorganized and much more documented [NovilloGCC2004] in the recent versions of the compiler. However, even the first intermediate languages used by GCC, namely Generic and Gimple, give already a quite low-level description of the program. This is very well suited for a compilation, but in the context of code analysis, some important information is lost with the higher-level constructions used in the original source. Moreover, as for the Edison parser, adding an annotation parser to the C++ front-end of GCC would probably have been difficult. Recently, however, Bjarne Stroustrup and Gabriel Dos Reis have introduced a representation for ISO C++ constructions, the Internal Program Representation (IPR) [ReisTR2005]. Such a representation is planned to be supported by GCC, and would be of much higher level than Generic. While this project is too young to be used in practice, it should be interesting to see if this format can gain enough maturity to become a certain form of standard representation for C++ programs.
We have already mentioned the Oink project. It uses its own front-end, called Elsa (http://www.cs.berkeley.edu/~smcpeak/elkhound/). Elsa and Elkhound, the parser generator upon which it is built, have been written by Scott Mc Peak at the Berkeley University and are available through a BSD license. While Elsa itself is written in C++, it forms also the basis of Olmar, which provides a strong embedding of Elsa's internal representation into Ocaml. Moreover, although Elsa is at an early development stage, it already covers a fairly good part of the C++ standard. In particular, it handles almost all the constructions used in Pistachio. Moreover, it is aimed from the start at providing a front-end for an analyser, so that its internal representation contains all the constructions used in the parsed program, without any transformation meant for compilation optimization. In addition, Elsa is relatively small and well structured, so that adding the support for the annotation language is not so difficult. It has thus been decided to use Elsa as our parser.
As Frama-C is written in Ocaml, the same issue as for Olmar arose: we had to find a way to represent the C++ values manipulated by Elsa in Ocaml. The first release of Olmar came after the beginning of the work on Elsa, so that we built our own translation mechanism. In fact, the selected solution is to have a very shallow binding between Elsa and Ocaml. On the contrary, Olmar proposes a more heavy-weight approach, in which Ocaml structures are directly built by the C++ code through call-back functions. This allows for richer interactions between the Ocaml world and the C ++ world, but we have not felt the need for it so far. The core of the binding mechanism relies on the fact that the abstract syntax trees manipulated by Elsa are not directly represented by a set of C++ classes, but described in an *ad'hoc*, much simpler format, called ast in Elsa's terminology. This description gives rise to C++ classes through a tool called astgen shipped with Elsa. astgen generates, among other things, methods allowing to pretty-print the nodes of an abstract syntax tree, with all the information that Elsa can provide about the node. To obtain an Ocaml representation, it is thus sufficient to write a version of astgen that generates Ocaml types, together with functions to parse the pretty-printed output of Elsa. Additionally, the extension of Elsa by the annotation language takes mainly the form of new astfiles (modulo a type-checking phase which is completely internal to Elsa and does not have any impact on the Ocaml side).

4 so that it is possible to reproduce exactly the behaviour of a given compiler.

In practice, the analysis of a C++ file is described in Fig.6. First, it is pre-processed and the result is given to Elsa. Elsa performs the parsing, type-checking and elaboration of the C++ code, and outputs a representation of its abstract syntax tree, containing the information from the elaboration (in particular, name look-up for overloaded functions, instantiation of templates, definition of the implicit member-functions, implicit creation of temporary objects through the copy constructor, ...). This output is then parsed on the ocaml side to build an equivalent Ocaml representation. After that, this representation is translated in a C file, or more precisely into the structure of the CIL library that handles an untyped C file (*i.e.* the datatype used for freshly parsed files). At this point, CIL will take care of type-checking the result and transforming it into a normalized representation, upon which the analyses of Frama-C will be done. A small difference occurs in the output of the result of the analyses, though: during the translation process, global identifier names are *mangled* to avoid name clashes. For instance two overloaded functions cannot share the same name in the C translation. Similarly two symbols declared in different name spaces can share the same (short) name in C++, but must be distinguished in C. Mangled names, which follow the Itanium ABI (hence also the GCC mangling rules), are valid C identifiers (so that it is possible to print the translated code as valid C code, *e.g.* to use another analyser). However, they are barely readable for an human being, so that they are by default unmangled in the messages from Frama-C or in the GUI. The mangled format allows indeed to extract the original name from the mangled one.

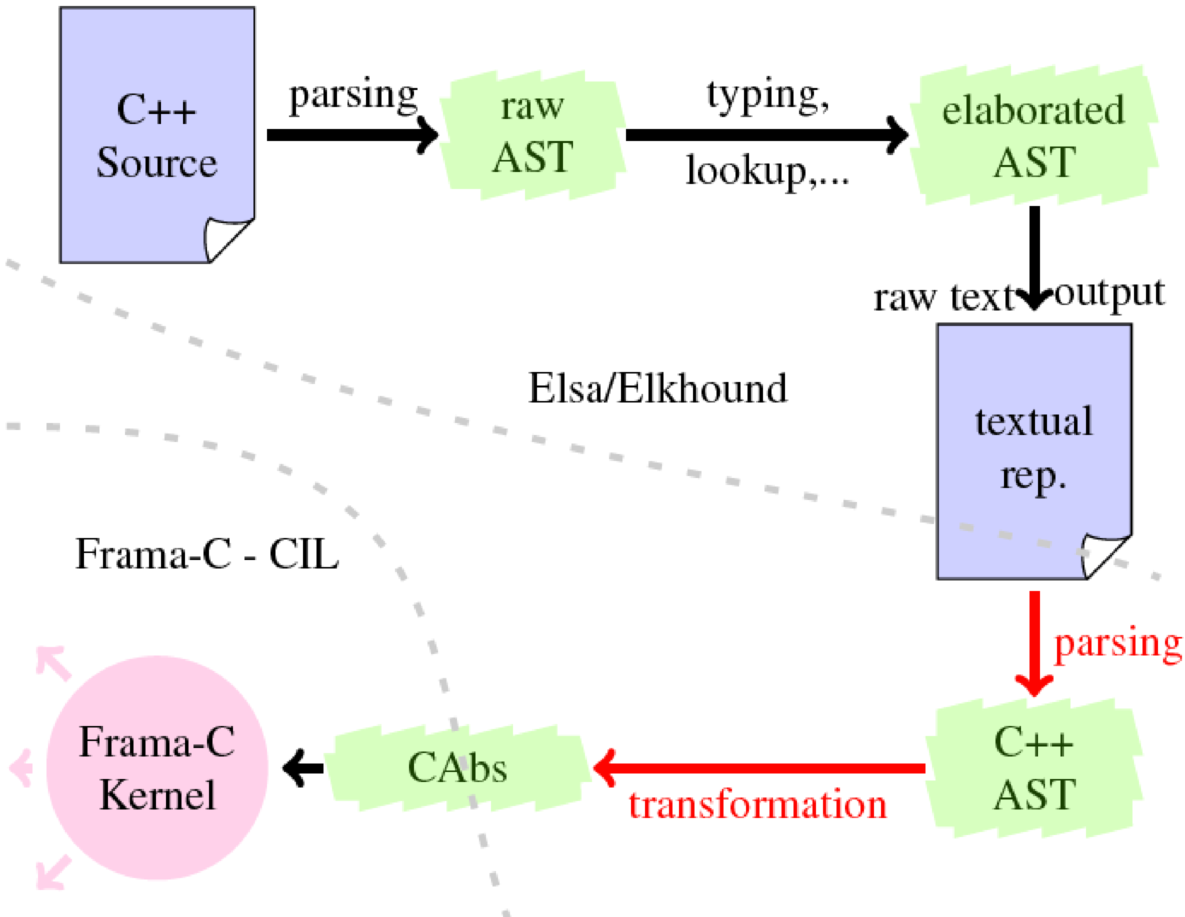


Figure 6: Processing a C++ file in Frama-C

As it can be seen above, a C++ file is type-checked twice during the whole process, once by Elsa at the C++ level, and once by CIL at the C level. In practice, the cost is negligible toward the time taken by the analyses themselves, and the type-checking pass done by CIL has two advantages. First, it is a good consistency check to ensure that the translation itself is correct. Second, and more important, CIL performs other things along with the type-checking, which do not have a direct counter-part in Elsa, such as the separation between side-effect free expressions and instructions that have a side effect, the computation of the control-flow graph of the functions, some normalization of function bodies, ... In order to target directly the higher layers of CIL, it would have been necessary to re-develop these analyses for the particular case of the C++, without any clear benefit for it.

5.5.3 Supported C++ Features

The set of C++ features supported by the C++ Frama-C plug-in has been progressively extended to support the Pistachio analysis. At the very beginning of the case study, only very few constructions were handled, mainly to serve as a proof of concept of the translation scheme presented in the previous section. This "initial state" of the plug-in included in particular the translation of the following features:

- The constructions directly inherited from the C language, that is the expressions, the statements, the basic types, ...;
- Basic classes (*i.e.* without inheritance);
- Reference types (as constant pointers);
- Overloading.

While these constructions are far from covering the whole C++ language, they already allow to write interesting programs, which were useful to fine-tune the interface between Elsa and Ocaml.
Once this interface has been stabilized, new features have been added when needed, following the experiments made on Pistachio code (see section 5.3 for details). The main enhancement concerned the handling of templates. In theory, all templates that Elsa knows how to handle are supported within Frama-C++. In practice, this is at least the case for Pistachio's templates. Some less visible but important C++ constructions were also added. This includes in particular the following points:

- Dynamic creation and destruction of objects (new and delete);
- Definition and use of user-defined conversion operators (including constructors with a single argument);
- Anonymous unions;
- C++ namespaces;
- static members;
- friend declarations;
- external bindings with C functions;
- Compound literals and compound initializations (GNU extension).

Other minor constructions have also been taken into account during Pistachio's analysis. Two main C++ features are still missing: inheritance (both simple and multiple) and exceptions. Given their complexity and the lack of a well-defined case study on which experiments could be conducted, there is currently no planned development to support them. Anyway, as will be shown in section 5.3, the current state of the plugin is already sufficient to perform an analysis of a significant part of the Pistachio kernel, without any major alteration of the code as it is distributed by the kernel developers.

5.5.4 Logical Annotations for C++

The annotation language designed for C programs mentioned in the previous section has also been lifted to C++. A C++ annotation is translated into its C counterpart during the processing of the whole program. Both flavours of annotations essentially share the same features, but a few adaptations in the C++ annotations have been made to allow for a more idiomatic style of logical formulæ. This includes in particular the possibility to attach predicates and axioms to a C++ class. Such logical definitions have then access to all the data member (public as well as private) of the class. Moreover, predicates, like ordinary function members, takes an implicit this argument to denote a pointer to an instance of the current class. Similarly, the specification of a member function can refer to the this pointer. On the contrary, axioms are more like static members: they are true in general, hence not tied to a specific instance of the class. Last, it is possible to declare invariants for a given class. Such invariants are a refinement of the type invariants that one can declare on the C side. Namely, the translation takes advantage of the structure of the program into classes to generate pre- and post-conditions for the member functions, based on the invariants of their respective classes. This specification generation is currently not as achieved as the work that has been conducted for Java, for instance in [BarnettJOT2004]. Nevertheless, it shows that a well-tempered usage of the high-level features of C++ can be of great help for the verification of a program. This is also the case for other validity assertions that are generated during the translation, in particular when dealing with references. References are indeed treated as pointers in the C translation, but by construction these pointers are always valid. This information is passed to the analysers in the form of a pre-condition of the functions that use reference arguments.

5.5.5 First Experiments

As explained above, the main experiments have been conducted on some system calls of the Pistachio kernel. More precisely, two system calls have been analysed, sys_thread and sys_schedule. In both cases, the amount of code considered, including the needed header files, was around 10,000 lines. The obtained CIL structures were roughly equivalent to 15,000 lines of C code. The abstract interpretation plugin of Frama-C is perfectly able to cope with the resulting code. No true alarm has been identified during these analyses. However, they are far from being complete. In order to do so, an exact description of what is a valid state of the kernel before and after the call under analysis would be needed. Such a task is highly complicated and must be performed in close cooperation with the kernel developers themselves.

Another line of experiments has been dedicated to see how to express formally the properties expressed in English in the API documentation, so that they can be taken into account by Frama-C. The most promising approach so far for the use of the abstract interpretation plugin consists in using ghost code to build a reference implementation (in the sense of [ElphinstoneHTOS2007]) whose results can be compared by the plugin to the one given by the actual implementation. For instance, a partial specification of the sys_schedule sys call, for the case were it is supposed to set a new priority to the destination process can be done like this. We start from the API documentation, which states the following:

> The system call can be used by schedulers to define the priority, timeslice length, and other scheduling parameters [...] The system call is only effective if the calling thread is defined as the destination thread's scheduler.[...]
>
> dest Destination thread ID. The destination thread must be existent (but can be inactive)
>
> All further input parameters have no effect if the supplied value is

-1, ensuring that the corresponding internal thread variable is not modified. The following description always refers to values different from -1.[...]

prio New priority for destination thread. Must be less than or equal to current thread

First, we define the ghost structures, and the function that models the real call for this structure. The structure as well as the function is a direct translation from the API documentation, which makes it easy to ensure that it is correct.

```
/*@ ghost struct ghost_tcb {
  bool existing; prio_t priority;
  ghost_tcb* scheduler;
  logic_global myself_global; };
*/


/*@ ghost ghost_tcb
  ghost_L4_schedule_prio(ghost_tcb& t, prio_t prio)}
  { ghost_tcb res(t); res.priority = prio;
    return res; }
*/
```

Then, we define a correspondence function between the real implementation and the ghost structure (as a ghost member function of the actual tcb class).

```
 /*@ ghost ghost_tcb& make_ghost() {
  ghost_tcb&
   my_ghost = ghost_global_tcb(myself_global);
  my_ghost.existing = exists();
  my_ghost.myself_global = myself_global;
  my_ghost.priority = priority;
  my_ghost.scheduler = &ghost_global_tcb(scheduler);
  return my_ghost;
 }
*/
```

Last, we add assertions to the actual system call itself, to ensure the conditions mentioned in the API documentation.

```
SYS_SCHEDULE (threadid_t dest_tid, word_t time_control,
                    word_t processor_control, word_t prio,
                    word_t preemption_control )
{
  tcb_t * dest_tcb =
```

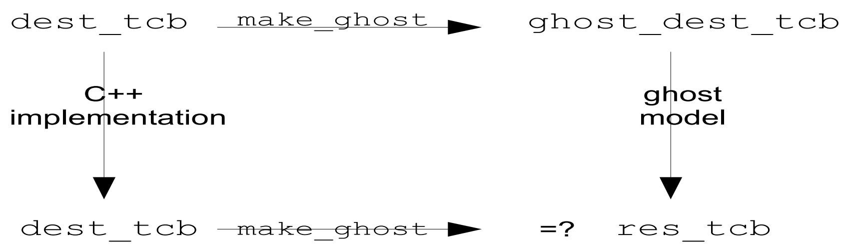
```
    get_current_space()->get_tcb(dest_tid);
  /*@ ghost ghost_tcb& dest_ghost_tcb =
              dest_tcb->make_ghost(); */
  /*@ ghost ghost_tcb& current_ghost_tcb =
       current_tcb.make_ghost(); */
  /*@ assert dest_ghost_tcb.scheduler ==
          &current_ghost_tcb; */
  /*@ assert prio >= 0 && prio <= MAX_PRIO; */
  /*@ assert current_ghost_tcb.priority > prio; */
  /*@ ghost ghost_tcb& res_ghost_tcb =
        ghost_L4_schedule_prio(dest_ghost_tcb,prio); */


  /*
  ... Normal operations ...
  */


  /*@ ghost dest_ghost_tcb = dest_tcb->make_ghost(); */
  /*@ assert dest_ghost_tcb == res_ghost_tcb; */
```

Namely, we use a ghost tcb dest_ghost_tcb that represent the destination thread, another one current_ghost_tcb for the current thread. These representations are used to check, through assertions, the requirements for the validity of the call. We then create a third ghost tcb, res_ghost_tcb, which is the intended result of the call (in the ghost model). At the end of the function, it remains to compare res_ghost_tcb with the ghost counterpart of the actual result, to ensure that they both coincide. Such assertions are successfully shown valid by the abstract interpretation plugin of Frama-C. The diagram below (figure 7) shows the property we want to establish: starting from the original `dest_tcb`, we can on the one hand extract from it its ghost model and use `ghost_L4_schedule_prio` on it, and on the other hand perform the normal operations of the implementation and extract the ghost model from the obtained thread. If the implementation is conforming to the model, we obtain the same result in both cases.

Figure 7: Correspondence between the implementation and the ghost model



Other, more axiomatic, models of L4 have also been proposed, but their verification would require the use of other Frama-C plugins, which are currently under heavy development. The current experiments show however that the analysis of significant part of the kernel, as well as the proof of some of their functional properties is definitely doable.

5.4 Static Analysis of XEN using Coverity

5.6.1. Overview

The second project year has been spent to apply static analyses methodology on XEN virtualizer to verify and validate its core and surrounding tools and libraries.

For basic analyses we selected the Coverity Prevent static analyser. The analysis process has been started with a detailed study of the analysis tool (year 1). In the past months Coverity Inc. periodically released updates and new versions of its tool. Every time some new features have been included and they extended analysis results and increased our understanding of the programming problems of the analysed system.

Together automated analyses have been applied extensive human-made investigation, analysis and filtering.

The results of this investigation process is a set of reports including large list of bug-candidates and a filtered list including near to 300 most important problematic points in the core XEN source.

5.6.2. Background

Static analysis is based on building data paths and call trees, and the analysis of modifications of data domains, belonging of modified data to unmodified domains, correctness of execution paths, etc. The previous experience of our group with analyses based on automata based models and very extensive knowledge of parallel and concurrent processes management, the C language and safe coding rules for critical applications made possible the extensive investigation on the XEN source code that is reported below.

From a historical point of view, investigations started with extended search on the Internet for messages, analyses and other material oriented to XEN. Mostly those materials were not helpful for our investigation but helped to form the basic idea that reported problems might result only from some problems when the application is handling abnormal situations.

5.6.3. Analysis process

The analysis process of such complex software like XEN is very complicated and needs a preliminary analysis of the system's structure, its building process and environmental dependencies.

Static analysis tools are applied to the analysed code in compile time. This is a very important limit. This is a limit because all source code that will not be compiled remains out-of-scope for the analyser. From another side, different compilations including different parts of the program's code make possible a second level of analysis based on the primary results. This second level analysis can be found unstable or dependent on the environment parts of the program or even changes in the program's behaviour dependant on compile settings. Additionally the results from the analysis stage will give extensive additional information about possible bugs in the code not compiled in the current run. The presumption for this is that similar pieces are very often written in a similar manner. Here a static analysis tool is generating templates for errors that have to be searched in the rest of the code.

The XEN system has a complex structure. It is adaptable to many hardware platforms including 32 and 64 bit processors. The composition process for a selected platform is based on conditional compilation where precise parts of the XEN source are selected and compiled. The selection process depends on many different settings and finally many different sources can be compiled for one and the same basic hardware platform. The number of these possible constructions is rather big and currently unobservable. We have no exact information about the influences between different variables settings.

The envisaged problem made simple observation on the XEN structure very hard. To resolve this problem our group installed and ran an LXR-based search machine. This made browsing the XEN sources non-ambiguous. Additional advantage of this decision was the possibility to compare the different versions of XEN together and to search for changes and code migrations. At this moment the LXR-browser hosts three versions of XEN – 3.0.3, 3.0.4 and 3.1.0.

The first attempts to analyse XEN were as follows:

- Analysis by Coverity Prevent,
- Manual analysis of the selected parts of the code.

The results of this study, as well as reading materials about static analyses tools (Coverity, Parasoft, Klocwork), led to the following conclusions about possible strategies for the use of static analysis tools for program validation and verification:

- **Full run**: the analyser is going trough the program and after the machine pass a manual analysis of the validity of the generated messages takes place.
- The analyser is used as **'standard' errors finder**. After a first machine run, an investigation of the whole source code is done with the errors already discovered. This is based on the the notion of programmers coding stereotypes:

preferred library functions, typical calling conventions, abnormal situations handling, etc. are often similar.
This method is very useful in situations as described above, namely for systems with a highly complicated set of conditional compilation rules. To build the full set of sources produced after a pre-processing pass and to send them to the static analyses tool is very hard task – it needs to have the full list of conditional compilation variables and rules and to know how their dependencies.

- The static analyser can be used as a coding rules checker. This usage is based on the following steps:
  - Coding rules definition and/or selection from a pre-defined list
  - Definition of sets of errors resulting from breaking pre-defined coding rules and analysing of the generated results
  - Applying the analyses tool as a coding rules checker for checking for violation of each one of defined rules.

5.6.4. Analyses of XEN's structure for conformance with static analyses limitations

The XEN core is a system controlling by default a huge variety of system resources (memory, peripheral devices, communication, threads, etc.). This definitely requires the design and implementation of an homogeneous approach for the error / rejection / misses handling for system resources requests.

The analysis of coding styles and programming stereotypes is required to identify possible typical errors or hives of errors.

- The first aspect of this problem is related to the presence of functions with one and the same name and with a "similar" functionality. In general these are functions where Hardware Adaptation Layer (HAL) hooks the upper levels of the system to different hardware platforms (e.g. 32/64 bits x86/ia64/PowerPC) or to different peripheral devices with similar APIs.

The investigation of the XEN code envisages a wide use of "***copy-paste***" approach for functions' implementation. This is main background for the next errors classes :

- Multiplication of one error in many functions.
- Hardware specific pieces of code can populate a hidden bad functionality in mirror functions oriented to different platforms/devices.
- Cloned functions targeting different platforms are exploiting different error distribution strategies. This follows to the situation where upper levels of the system are receiving different messages from one and the same function (of course – one and the same name and different body).
- The development of the XEN virtualizer is based on several different groups of basic functions::
  - GCC compiler libraries (UNIX-like standard)
  - LINUX system functions
  - GDB library functions
  - APIs to Phyton
  - API of XML C-parser

The dominating style is '***LINUX-like***' as it is referred in the computer science books. This conclusion is based on analyses of the implementation of templates for many basic functions (e.g. see string/memory manipulation library functions). Mostly these functions are implemented by copying their LINUX version instead of their UNIX standard. This becomes very clear when looking at the style of returned error-codes in functions allocating/releasing some system resources and additionally follows the question “why are they implemented again instead of using the available version?”.

5.6.4.1. Error handling styles

The existence of several different groups of ‘basic’ functions (see above) is very big hurdle for the design/implementation of homogeneous approach for error/rejection handling. Now in XEN one can see the following variants of error codes return in case of abnormal function end:

***A)* Functions returning pointer** as result

Table 9: Functions returning pointers

	unsuccessful service	successful service	*modification of ‘errno’* variable	Additional information
1	`NULL`	`every other value`	no	
2	`NULL`	`every other value`	`EPERM, EINVAL, ENOMEM, . . .`	In some cases some function parameters are used instead of *errno*
3	`‘error’ values (generated by macro ERR_PTR)`	`every other value`	no	

***B)* Functions returning numerical values** as result

Table 10: Functions returning numerical values

	unsuccessful service	successful service	modification of *‘errno’* variable	Additional information
1	`0`		`EPERM, EINVAL, ENOMEM, ….`	In some cases function parameters are used instead of *errno*
2	`0`	`1`	`no`	
3	`0`	`1`	`EPERM, EINVAL, ENOMEM, ….`	In some cases function parameters are used instead of *errno*
4	`-1`	`0`	`no`	
			`EPERM, EINVAL,`	In some cases function parameters are used

5	-1	0	ENOMEM, ….	instead of *errno*
6	-EPERM, -ENOMEM, -EINVAL, ….	positive integer value	no	
7	negative values (-3,-4, -5, -6, …)	positive integer value	no	
8	false	true	no	
9	false	true	EPERM, EINVAL, ENOMEM, ….	
10	positive values by catalogue	other codes (mainly 0)		

C) **Execution halting in case of error**.

Execution halting in case of error – this aspect of system reaction in case of internal problem is widely used. Here we do not comment whether it is reasonable or not, but only about its existence. As we will see later in this document, the reason to use this type of reaction has to be proven in a much wider work for exception handling. The following versions of this reaction were found

- Direct call to the *panic()* function
- Two macros defined in XEN (*BUG* and *BUG_ON)* are calling *panic()* internally
- Explicit call to *exit()*
- Functions calling *exit()* indirectly, i.e. inside their body

D) Error messages are reported on screen and/or files but reporting function continues ***to use*** just reported ***non-operational*** resource(s).

E) Ostrich approach - no kind of abnormal situations check and handling.

5.6.4.2. Conditional compilation

The XEN source is based on very extensive exploitation of conditional compilation. This is a key problem for static analysis tools. The analyzer checks the source code at compile time. To analyze a program using conditional compilation, we must run it through the static analyzer for each one of conditional keys combinations. This is time-consuming but is possible when a full list of conditional keys is available and when dependencies between them are known.

A second problem is related to the fact that generation of files for separate compilation is setting-up 'include directories'. In case of XEN this problem is additionally complicated by the use of options for machine dependency checks. This influences conditional compilation in the main roots. This leads to the situation where *make* files have to be manually changed/ adapted for analyses purposes (full tree coverage).

The third problem is related to the problem that static analyses tools and coding rules checkers require knowing the type and the version of the compiler in use. This creates a new group of problems based of non-portability in main code and libraries, and standards' conformance checks.

5.6.5. Investigation methodology

XEN verification is done by using a static code analyser in the following scenarios:

- 'Template error' generator.
  This scenario is based on main coding style (see above). The resulting templates are used for code mapping in all files without any dependence on the target platform and specific hardware.
- A coding rules checker
  The indispensability of these analyses is explained in 5.6.4. Coding rules used in these analyses are defined in general in the "Management report - Appendix 3 - Linux errors.pdf" presented Oct. 2006. In §II.2.2 are presented some typical error sources making implementation of these rules much more necessary. Presented results prove this affirmation.

The static analyses tool selected for investigation in XEN code is *Coverity Prevent*. A limited license for it has been bought.

Some additional input was obtained from the evaluation version of Parafost's *C++Test* analyser, too.

A major impossibility of static analyses tools is to find errors generated by differences in the type of actual parameters passed to a function and formal parameter's prototype ("type mismatch"). To solve this problem we extended the analysis using *GCC's* 'warning' options. With options '-Wall' or '-Wmissing-noreturn' *gcc* generates warnings giving points to find and remove many errors. The major problem here is conditional compilation again. It is not resolved now.

Only files of type '.c' and '.h' have been analysed.

All other sources ('.patch', '.py', ..) are out of scope of this investigation.

Additionally a tool for analyses on the primary report documents has been developed. This tool makes possible different kind of filtering, analyses and statistics based on the primary reports.

Under development is a tool oriented on analyses of call trees (called trees and calling trees). This research is oriented to produce environment for deeper understanding of possible importance of problematic code pieces envisaged in primary reports. Results will be used to prepare additional priority scheme for bug-candidates filtering.

After April 2007 basic technology for XEN verification has been split in two parts:

- Basic investigation based on the above reported methodology
- Preparation of new methodology for prioritisation of reported errors for better organisation of bug-fixing activities.

Work for investigation of possible errors/weak places resulted to the following list of reports, included in appendix:

- XEN 3.1.0 - Error Report - Appendix 2.1.pdf
- Error Report - Appendix 2.2.pdf
- Error Report - Appendix 2.3.pdf

- XEN 3.1.0 - Error Report - Appendix 2.4 - return NULL.pdf
- Error Report - Appendix 2.5 - XEN 3.4.0.1 - unsigned function returning negative values.pdf
- Error Report - Appendix 2.6 -XEN 3.4.0.1 unchecked negative error and return codes.pdf
- XEN 3.1.0 - Error Report - Appendix 2.7.pdf
- Error Report - Appendix 2.10 - returned negative codes.pdf
- Error Report - Appendix 2.13 - unchecked PTR_ERR.pdf
- Error Report - Appendix 2.13 - XEN 3.1.0 – ASSERT.pdf
- Error Report - Appendix 2.14 - unchecked codes (-1 and OF_FAILURE)-upgraded.pdf
- Error Report - Appendix 2.16 - unchecked codes (0 or 1).pdf
- Error Report - Appendix 2.17 - unchecked codes (0 or !=0).pdf
- Error Report - Appendix 2.18 - unchecked TPM codes.pdf
- Error Report - Appendix 2.19 - unchecked IA64 codes.pdf
- Error Report - Appendix 2.20 - unchecked SHADOW_SET_ERROR.pdf
- XEN 3.1.0 - Error Report - Appendix 2.21 - ASSERT.pdf.

All these basic report files give enough data for more detailed analyses of error targets.

A custom tool for the analyses of basic reports has been developed. This tool implements analyses a selected list of files, types of errors and their frequencies, types of targets and includes some statistics features and other cross-related data-base queries.

In June 2007 a first set of filters has been defined. They are (in priority order):

- XEN core sources,
- No init functions,
- No HAL functions.

With these filters a list of targets has been prepared. This list was made together with CUCL.

5.6.6. Investigation results

The analyses of the coding style of XEN started with XEN version 3.0.3. and continued through version 3.0.4. and now covers version 3.1.0. Approx. 3000 errors or possible dangerous pieces of code have been found. Approximately 1900 of these errors have been reported.

After the release of version 3.0.4.1, the error reports have been revised. All other analyses and reports are based only on this newer version.

The results can be classified into the following categories:

- Memory allocations: Missing control about the validity of memory manipulations is one of the most general and common programming errors leading to serious problems. A few variants of missing control were found but the most important is immediate use of allocated memory without control about successful allocation. A set of 123 functions is investigated.

- File manipulations: When using files as inter-process communication media one of the most dangerous errors is non-checking of returned codes of file manipulation functions (success or failure). The current version of XEN has a huge number of potential problem candidates (about 1450). Example: almost all calls to *fprintf* are unsafe.

- Unchecked returned error codes: Near to 340 errors have been found in 232 functions. Analysed functions are library functions of *GCC, GDB, LINUX system functions, APIs for Python*.
- Unchecked NULL pointer when returned as error code: These errors are described in ***5.6.4.1.*** table 4/#1. More than 230 functions have been analysed. About 134 of them include unsafe/unstable code.
- Unchecked negative error and return codes: These errors are described in ***5.6.4.1.*** table 5 / #5 and #6. This is not a special kind of error but specific situation when some negative values are used to describe the type of the error situation. Some of results are left for export to other functions and some are used immediately (for example as *bit* and *boolean* operands). Additionally in many cases the returned code is used directly for array access (indexing) where negative value directly access areas outside the array. This can be security problem, too.
  About 500 errors have been found in 175 functions. More than 1171 functions have been analyzed. All of them are XEN-specific.
- Functions returning wrong error codes: This error is specific to functions returning negative values but having a return type declared as *unsigned*. The result of this type mismatch is an impossibility to pass a correct error code to the calling function and possibly – generation of wrong values as result (negatives will be interpreted as big positive numbers). Investigations found 73 functions of this type.

5.6.7. Analysis conclusion

All established coding templates and errors are leading to the following conclusions about XEN status:

1. The major fault is the lack of a homogeneous approach for abnormal situations handling. One of the most problematic defects is that functions applicable for different platforms having similar (or one and the same) functionality are using different strategies to return error codes. Moreover, there are situations where in one implementation the function returns some error code(s) and in the other implementation does not.
2. An error handling is mainly reduced to simple checks of the type "success/failure". At many places an adequate diagnostic is possible but is omitted and substituted by a simpler check. The result of this is a reduced level of safety and redundancy of the system. This type of error handling mainly leads to system reactions like those described in ***5.6.4.1.C.***

3. A very important problem is the impossibility to do exact error analyses due to the integration of several functions exploiting different and contradicting error-message propagation systems. This situation becomes clear when one function returns a result generated by another function (called inside) and they are using different types of error-message propagation conventions. The most common problems are:
   - Functions generating error message/code shown in ***5.6.4.1.*** table 1/ #1 and table 1/#3. In this case neither checks by IS_ERR macros nor checks by "prt == NULL" can be used.
   - Functions generating negative error messages/codes. In this case the error code '-1' is equivalent to '-EPERM' and thus leads to ambiguity in error code values.
   - Functions returning error codes via the global variable '*errno*' do not take in consideration possible influences of system and library functions of *GCC, GDB and LINUX*. In this case the call chain may lead to a modification of '*errno*' and a loss of the original error code. A trace of these errors with static analysis tools is mostly impossible and needs a behaviour validation tool based on very detailed description of all libraries and system functions.

5.6.8. Suggestions

As a result of all currently done investigations and analyses, we suggest the following:

- Design and implement an homogeneous approach for errors and abnormal operations handling.
- Cancelling a task should be done only in the case when a continuous impossibility for its operation is detected.

5.5 Static Analysis of XEN using Frama-C

5.6.1 Overview

With the Frama-C prototype tool, based on AI, and described above and in the previous D07.1 deliverable, we investigated further the code of XEN 3.0.3. This tool being a prototype, the analysis was progressing in parallel to the development of the tool and in close cooperation with its developers.
The analysis of XEN 3.0.3 must be considered as an experiment, whose aims are threefold:

1. Discover as much as possible bugs in the source code of the target set.
2. Improve the tool: bug reports and suggestions of improvements shall be sent to the authors.
3. Compare the results to those obtained by other static analysis tools of the same nature (i.e. based on AI), which is Coverity Prevent in our case. This is left for year 3.

5.6.2 Background

The first year set up a certain number of targets, that developers of OpenTC OS deemed to be most important, and therefore critical for other OS developments.
Of course, the stable components on which OpenTC is based, were considered first, as

they provide quite stable and debugged code. XEN is of such a kind, as numerous users and developers use and experiment resp. with this product, forming large developers and user bases. Please see the users and developers mailing lists on http://lists.xensource.com/.

The first project year has also allowed to develop the core parts of the Frama-C interpreter, allowing us to play with it, but with some developers guidance. The GUI and other plug-ins were developed along the project, to improve its usefulness and capabilities for analysing C code.
The foundations of Frama-C are explained in D07.1 as well as in the section above related to the improvements of Frama-C. We will not come back on this.

5.6.3 Code analysis process

The analysis process is a continuation of the process of analysing XEN 3.0.1, started in year 1. Please refer to D07.1 for reminding how we had done this.

During year 2, we have done the following steps to analyse XEN 3.0.3 in turn:

- Installation and testing of XEN 3.0.3 on PC/Linux x86_64. This was again chosen as the target platform for our investigations, but x86_32 and PAE should be considered too. Most PC are now x86_64 architectures, which is why we continue to invest in that target.
- Stripping the code: the source code concerning other platforms than x86_64 AMD was removed from the source, to make the next steps more efficient.
- Porting of the source code changes done to XEN 3.0.1 to XEN 3.0.3: this is rather tedious as it was done by hand. Much code having changed in the new version, we only ported changes to the common code, and did some changes to the new source code when necessary. This means that, whenever possible, we replaced the x86_64 assembly code by some C code.
- Adapting the analysis launchers: some scripts were made to launch the analysis of each target function, and some main C functions were written to call the targets with a proper context.
- Enrich the context of the main functions whenever some new context data (constants, variables, types and functions) appeared.
- Iterating with the static analyser until the targets are fully analysed and the maximum number of potential errors were gained, or until severe divergence appeared: this required to follow he evolutions of Frama-C and understand when the analysis was in difficulties. Indeed, in most cases, the analyser got stuck because of some “divergence” or error. It was decided by the Frama-C developers to stop an analysis whenever the imprecision was too large, for instance when a pointer can refer to any address. Sometimes the interpreter was also at fault, which led us to report problems to the developers. At every such divergence, we investigated the root causes and proposed a solution, mainly by changing the code slightly (simplifying it).
- Keeping track of the anomalies encountered as well as the code changes: most anomalies are reported in the appendix 3 of this document. Code changes were handled by copying modified source files into another directory (named `top`) which mirrors the original `xen` kernel main directory. File names were kept and markers were added to the code to indicate the nature of the changes.
- Log the difficulties encountered in the analysis process.
- Interact with the XEN developers when we suspected some severe anomalies or

when we doubted about their cause (either because of the analyser's misunderstanding/limitations or our own understanding of XEN): we mainly interacted with the OpenTC CUCL team.

5.6.4 Main results achieved

Using the above process, we concentrated on 5 hypercalls and the main initialisation function of XEN.
For every such target, the analyser produced large output data. This data contains a mixture of code traversal traces, warnings, alarms, state traces and manual trace reports. The Frama-C GUI finally improved recently, allowing us to understand easier this volume of data. Now the GUI allows to browse the code and its CIL pre-processed version, and examine the content of some variable or expressions at locations traversed by the interpreter.

Notwithstanding its limitations, from the Frama-C user perspective, we were mainly satisfied with its results. For every target function, the traces were filtered and every warning was scrutinized by hand, in order to report details about it and decide, whenever possible, about its nature, namely 'false alarm', 'real bug' or 'unknown'. The result of this work is found in appendix 2 of this document, where the reader will find detailed warnings classified per target and bug category.
Below, we provide a description of the categories of warnings that we met during the analysis, the main obstacles encountered and synthetic results of the analysis. These later quantify the warnings per hypercall.

5.6.4.1 Error categories

Of course, we did not use all capabilities of Frama-C and therefore did not meet every kind of error.

The table below gives the list of error categories that were detected in XEN. Every error is presented textually with the format:

`<location>: Warning <error message>`

where a location has the form <absolute file name>:<line number>
and <error message> follows some error category (see below) with parameters instantiated. Parameters can be another location, a variable or function name, etc. helpful for debugging the error.

Table 11: Categories of potential bugs

	Category	Semantics
		and error message form
		`Some variable when read or written has a value lying out of its declared domain. For`

1	Out of bounds	instance, an int might be out of the interval [-2**32,2**32-1], an index to an array might be out of the declared index range, etc.
		Out of bounds read/write
2	Precondition unsatisfied	The code might be annotated with simple pre- and post-conditions, that are associated to C functions, and that the AI interpreter understands. Whilst the interpreter traverses the code it meets assertions, that it checks for satisfiability. Three cases might happen: • Precondition satisfied: its value is true in the current state. In this case, the assertion strengthens the state calculated by the interpreter, allowing it to continue its analysis with a better state. • Precondition is unknown: the interpreter does not know in the current state. • Precondition not satisfied: the assertion is certainly false.
		Precondition of <function name> got status valid/unknown/invalid
3	Missing return statement in function	Self-explanatory
		Body of function <function name> falls through. Adding a return statement.
4	Incorrect return statement	A function that declares to return void has a return statement.
		Return statement with a value in function returning void.
5	Incompatible declaration	Something is declared differently than implemented. Mostly for functions. This is severe error.
		Incompatible declaration for <item_name>. Previous was <location> (different constructor: <parameter> vs. <parameter>)

6	Different declaration of a global	Some global item is declared several times, but differently. This is a severe error, meaning that an important item is used differently in different portions of the code.
		The name <item name> is used for two distinct globals.
7	Volatile global variable initialized or missing constants initializations	Volatile variables do not need to be initialized. When this is still detected, the interpreter warns that the initialization done is useless and therefore not considered.
		Global initialization of volatile value ignored. **No initializer for the const variable <name>**
8	Constant not initialized	Self explanatory.
		no_initializer for the const variable <name>
9	Unknown size	Sometimes variables cannot be initialized because of unknown size.
		Cannot provide a default initializer: size is unknown
10	Addresses comparisons	Comparing addresses to fixed values in memory is something very dangerous, as addresses might change or types may change during time, so the interpreter warns when addresses are compared to constants or other addresses.
		Threat: comparing addresses
11	Divergence	The interpreter is said to diverge when at some location it has too much imprecision (generally on some pointer). The actual version of Frama-C stops the code traversal of the current path then and displays the warning below, querying the user to search the reasons of the divergence. Of course, if there is just one path, the interpreter halts the code traversal, otherwise it continues with another path (for instance, another branch of a conditional statement).

		Warning: all target addresses were invalid. This path is assumed to be dead.
12	Others	Quite rare errors include: incompatible pointer size, uninitialized constants, etc.
		All other messages.

5.6.4.2 Main obstacles encountered

The progress of the XEN analysis experiment was punctuated by obstacles, which are noteworthy to report. As every application analysed with such tools is very different, this report may be reused with benefits.
The main obstacles encountered are as follows:

- XEN 3.0.3 could not be compiled with gcc 4.1 as it led to a corrupted kernel image. Using gcc 3.3, as recommended in the user manual, went well.
- Use the xentools to build easily some domU, as the networking configuration of several domU is tricky. It works best when installing predefined Linux domU, such as Debian Sarge.
- Assembly code found in xen-3.0.3/top/include/asm: the includes have been modified and new functions created in file xen-3.0.3/top/xea_4asm.c. The later file groups all new C functions that replace assembly code. In file top/include/asm/procesor.h remain some assembly functions, quite difficult to replace. Similarly in files xen/include/asm/x86_64/asm_defns.h and xen/include/asm/msr.h.
- **Interrupts and registers**: these are CPU parts that we could not represent well. The later were ignored and are a research subject: interruptions can break the normal flow of control of XEN and change, during the execution of interrupt handlers, some values I the global state of XEN. When control resumes, the state might be different. Interrupt handling was removed. For the later, we introduced extra variables and structs to model the x86_64 64 registers. Macros SAVE_ALL and RESTORE_ALL were changed accordingly.
- **Paging**: the analysis of the initialiser __start_xen was stuck when the paging system was initialized (see file arch/x86/x86_64/mm.c) or used. The cause is rather deep, as Frama-C only uses one level of memory representations, namely real memory. No model exists for virtual memory, that is managed using the paging sub-system. This is a research problem in its own. At the source level, the analysis was hindered when virtual addresses are transformed by the paging system, especially when addresses were cut into pieces, necessary to get new adresses. A first idea was also to disable paging at the CPU level, namely by setting in processor.h X86_CR0_PG=0, and also add an extra variable CR3 and try to mimic the page management functions by dummy code. This was not a success as paging functions are used an numerous places. After some experimenting, we decided to stop the analysis of __start_xen.
- SHADOW and GUEST PAGING_LEVELS: two macros are used to represent the paging system levels of the host and guest machines (dom0 and domUs). These are used in file multi.c which is compiled several times by the XEN Makefile. With our reference architecture, 3 combinations remain 4-4, 3-3 and 3-2. We decided to pre-compile multi.c with these settings, replacing it by 3 source files.

- String management functions: string operations are implemented efficiently, but their code generates numerous warnings by Frama-C. Indeed, arrays of chars are not well handled by the interpreter.
- Bitops.c: bit manipulation functions of this file were cmpletely replaced by equivalent C code.
- Undefined functions: Frama-C is capable of listing the set of functions whose code is undefined. Some are missing because of they are implemented by assembly code only, that the interpreter cannot see, and some are stubs. Examining carefully this list allows to check if they are useful or not for the analyses at hand. If this is the case, we can add extra hand-written code, to approximate them.
- **Efficiency vs. precision**: many global variables were added to the man fuctions to model some domain with default data. This data contains numerous struct and tables. With the default settings, tables are harshly approximated by one element, which leads to heavy approximations later on. The interpreter can be forced to model the tables correctly, but this leads to prohibitive analysis execution times: several hours instead of less then 30 minutes. No satisfactory compromise has bee found.
- **Linker trick**: in file percp.h the macro DEINE_PER_CPU serves to represent arrays of CPU specific data by arrays. The arrays are indexed by CPU numbers, but only the CPU data blocks are known in the C code. The array is built using a trick of the linker that consists in forcing the data blocks to be stored in a specific extra segment. We decided to make these arrays explicit as transform the associated macros accordingly.
- Alignment directives are ignored by Frama-C. Analyses can be done without this kind of data.
- **Hypercall arguments**: when analysing the target hypercalls (see below) we had to build a context for each one, modelling what has already happened in a XEN system, especially domains data. When such code is analysed, Frama-C rebuilds missing global data with a very approximated manner, in order to have some useful data. To perform some precise analysis of each hypercall we tried to find the best possible values of the arguments of each hypercall. Each hypercall was associated a main routine, where the context is built and where actual values of the hypercall arguments are assembled into arguments. The cooperation of CUCL was required in order to define these arguments properly, leading to a code analysis as precise as possible.
- **Pointer arithmetics**: this is a notable basic problem, as the interpreter does not handle well the transformation of pointers. Actually, Frama-C understands when references are shifted to a further location, but only if the variable referenced contains the right type of data. Doing pointer arithmetics by cutting and pasting parts of the address, such as done in the paging sub-system, is not well understood.

5.6.4.3 Synthetic results

The following tables give resp. the number of warnings per category of bugs and their classification into 3 types of warnings.

Table 12: Bugs per categories

Hypercalls/categories	1	2	3	4	5	6	7	8	9	10	11	12	Total
do_mmu_update	24	11	2	8	7		27			4		1	84
do_grant_table_op	1	1										1	3
do_memory_op	2									3		2	7
do_domctl													0
do_page_fault	1												1
__start_xen	54	10		1	1		4			2		3	75
Total	82	22	2	9	8	0	31	0	0	9	0	7	170

Table 13: Bugs statistics

Hypercall/bugs	False alarms	Unknown alarms	Confirmed bugs	Total
do_mmu_update	9	60	15	84
do_grant_table_op	0	3	0	3
do_memory_op	3	4	0	7
do_domctl	0	0	0	0
do_page_fault	1	0	0	1
__start_xen	7	66	2	75
Total	20	133	17	170

Notice that the number of bugs cannot be related to the hypercalls, as we have analysed hypercalls in the following order: first we spent much time with __start_xen, and then we analysed the less complex hypercalls. For each hypercall, we report only new errors discovered, and left out those already found in previous hypercalls.

We notice a large proportion of open errors, mostly related to bug category #1, and found in the first hypercall and the initialisation function. These warnings are very similar and repeated. A few confirmed low-level bugs were found in these same functions (see appendix). The ratio is about **10% of confirmed faults**. One might also notice that no warning of the categories 6, 8 and 9 were found, allowing us to remove these categories from the tables. 7 warnings in category 6 were found on hypercall do_grant_table, but not reported here as they are already handled through other bug reports. Categories 8 and 9 are present here as we had discovered some of them with previous versions of Frama-C or XEN only.

5.6 On-going work and future directions

Currently, TUS and CEA are planing to terminate the static analysis of the selected functions of the XEN hypervisor at then will merge the results in 2008. As BME is testing the same target with results available in 2008, the merge will include the results of BME too. It is planed to report this in June 2008 (M31).

During the next year, TUS will analyse selected components of L4/Fiasco using Coverity Prevent, whose results will be combined with the L4/Fiasco testing results obtained by BME. During the same time, CEA will analyse OSLO with Frama-C.

Of course, other software components might also be selected based upon internal discussions and agreements within WP7 and the project management.

6 Feasibility study: Xen and Common Criteria EAL5 evaluation

6.1 Overview

Common Criteria is the most recognized security evaluation and certification methodology on an international basis. Its results influence investments into IT solutions for an increasing amount of industry and government verticals where security considerations are of major importance. The Evaluation Assurance Level (EAL) range from EAL2-4 is referred to medium assurance, EAL5-7 would be medium to high assurance. All widely used and current medium systems (such as general purpose utility computing Operating Systems) are limited to EAL4 due to intrinsic considerations of their design and the (non-formal) methods used for designing and implementation.

Since virtualization is often expected to improve the overall security of a system by providing a separation layer to contain workloads at a lower level than the Operating System works at, the trust value that comes with virtualization is considerably important. It is desirable to achieve a higher level of assurance in the virtualization layer so that trust related statements about the software subject to the virtualization layer's containment functions are equally trustworthy.

SWP07d aims to study the feasibility of the Xen hypervisor to undergo Common Criteria evaluation at Evaluation Assurance Level 5. The result shows high confidence in the statement that such an evaluation would not be successful for a variety of reasons, both related to design, architecture and processes, to the degree that such information is publically available. Independent from the result of the study, it outlines how the Security Target for a Common Criteria evaluation needs to be architected based on the desired functionality and the minimal security functional requirements commonly anticipated for virtualization solutions to achieve maximum assurance.

For this study, a reader's basic knowledge of Trusted Computing technology, specifically trusted boot path notations as well as TPM functionality, and paravirtualization architecture is expected. The study accounts for presence and the operation of Trusted Computing components such as a (hardware) TPM, a virtual TPM driver native to Xen as well as all boot path components being Trusted Computing aware. The purpose of these components in the system can be generically outlined as to be able to identify which software has been transferred control to over the machine or parts thereof, for each step in the startup process of the system, and to serve Trusted Computing functions as provided by the TPM and his higher layer drivers and interfaces (TSS). It should be clear that trustworthyness of all statements that originate from Trusted Computing components are only as strong as the trustworthyness of the software entity that retrieves information from Trusted Computing components and articulates them. In this document, whenever Trusted Computing components matter in conclusions drawn, blue text background is shown.

For the purpose of this study, the differences between the two supported hardware architectures Intel 32bit (i686) and AMD/Intel 64bit (x86-64) are intentionally disregarded.

A manual source code audit of the interfaces that are exposed to guests by the Xen hypervisor is being conducted to allow for a comparison of the findings with the results of other subworkpackages of WP07. This audit report will become available in January

2008. Its content do not influence the conclusions drawn in this document, but shall give an indication on the quality and hygiene applied to the source code of the hypervisor, based on subjective experiences gathered with source code audits on a professional background.

6.2 Availability of documentation

Documentation about Xen is available from http://www.xensource.com/ and from http://www.cl.cam.ac.uk/research/srg/netos/xen/ . Documents downloadable from these locations abstractly describe the basic functionality of Xen's implementation of paravirtualization in whitepapers, as well as user guidance for the use of Xen.

The author is not aware of the availability of High Level Design (HLD) documentation on Xen.

The existence of Low Level Design (LLD) documentation is unknown, too, and anticipated to be much lesser likely than High Level Design documentation.

The absence of these two integral documentation documents or lack thereof directly impacts the progress of this study. Presentations available from the websites above indicate the methods used by the two supported hardware architectures to implement the hypervisor's memory protection model, but beyond any detail referring to the design. Xen is Open Source Software; the development model invites contributors and enthusiasts to inspect the source code directly. High- and Low Level Design documentation should however be the basis for any investigation about the correspondence between design and security objectives. Its absence denotes the **first blocking item** in the feasibility of a Common Criteria evaluation (EAL3, 4 and above).

In the further course of this document, the LLD and HLD absence is being ignored while avoiding references to potential content where it would be desirable. If necessary, such content is projected from other, related sources, at the corresponding detail level.

6.3 Xen architecture and immediate implications

The Xen architecture consists of multiple functional parts:

- a hypervisor
- dom0, the privileged domain
- domU, unprivileged domain(s), guest domain(s)

The hypervisor is the only instance of the stack that has unconstrained access to all hardware of the system. dom0 makes use of the resources and the hardware access controls that the hypervisor allows to the hardware, while other, so-called guest domains are shielded from the hardware by the hypervisor. The storage, video, audio and networking devices accessible by a guest are “virtualized devices” that the hypervisor offers to them. Those “virtualized devices” are re-routed accesses to I/O resources that dom0 must provide in the scheme of a client-server model.

Consequently, by intentional design, the hypervisor does not contain device drivers for hardware components of the system itself (exception: Virtual TPM driver, rudimentary disk driver). The hypervisor only mediates memory accesses and CPU usage (note: access to mapped memory regions of hardware that is connected through a bus in the system (DMA) is treated similar to a regular memory access), masking its guests by running them in the CPU rings (Intel architecture privilege levels) 1, 2 and 3, reserving ring 0 with unconstrained access to all resources of the system for itself. For the 32bit architecture, the Xen hypervisor makes use of memory segmentation to protect memory accesses from guests into the hypervisor's memory regions, which accounts for the high performance of context switches between a guest and the hypervisor – page descriptor table changes would be too slow. The segmentation processor-level control is not available on the 64bit architecture due to optimizations done by the processor manufacturers in anticipation that the segmentation memory model would not be needed any longer for the 64bit systems. For the 64bit platform, the hypervisor is protected at the page level.

Creation, delegation, separation and destruction of guest domains is mediated by the hypervisor and requested for by dom0 through the hypercall interface that also governs I/O to and from the guest domains. Both the dependency of I/O and domain separation functions on dom0 constitute the trusted status of all components in dom0, particularly the dom0 kernel. All current general purpose utility computing Operating Systems that are suitable for serving as a dom0 host system for Xen can reach Evaluation Assurance Level 4, but no EAL beyond 4.

Consequently,to go beyond EAL4, this dependency must be removed by either a different design (unlikely) or by not claiming the Security Functions inherent to this dependency. This means that dom0 is essentially removed from the TOE so that no operations of dom0 influence the TOE; in more detail:

- For I/O:
    - The Target of Evaluation (TOE) Security Functions (SF) (TSF) cannot claim to provide the integrity, confidentiality and availability of data served to domU guest domains by dom0.
    - The guests (domU) cannot rely on the integrity, confidentiality and availability of data served by dom0 through (para-)virtualized storage and network devices, as well as all other devices that are served by dom0.
    - These controls must be provided by the guests themselves, potentially through the use of cryptography technology applied to storage and networking. Please note that integrity is often just assumed to be a benefit of cryptography, but not necessarily granted. Storage keys must be supplied by the hypervisor, who may make use of its native TPM driver to store such keys (TPM sealing).
    -
- For separation, creation and destruction of virtualization domains:
    - the hypervisor must be run in a static mode with a boot-time configuration that is part of the TOE and that allows no further changes to the system. Creation or destruction of other guests may be permitted by the hypervisor if such configuration changes leave existing guests unaffected. This TOE boot-time state must be measurable by Trusted Computing components. OR:
    - further run-time configuration changes must be prevented after the system has been transferred into the TOE specific run-time configuration. This TOE run-time state must be measurable by Trusted Computing components.

- The dom0 privileges must be constrained to hardware access and must not allow accesses to other guest domain's memory regions. (In this particular point, intended design may differ from implementation, depending on the version of Xen, due to ease of programming simplification! (!))
- Bootables must be measured using Trusted Computing components by the hypervisor without any dependency on functions or resources provided by dom0 by the time of the measurement. Due to the concurrency of other guests (this includes dom0!) who potentially manipulate bootables during the measurement, the execution of contexts outside the hypervisor must be suspended from the time the measurement takes place.

On the hardware architecture in use today, PCI bus systems provide DMA for high performance data exchange between peripheric hardware and the core memory of the system. Drivers (that run in the dom0 kernel) can potentially manipulate the hardware to write to memory regions that are not subject to the MMU functions and memory protection mediation of the processor. DMA (currently a chipset function, not a processor function) mediation mandated by the processor is not possible with today's hardware. This constitutes the **second blocking item** in the feasibility of a Common Criteria evaluation (EAL3, 4 and above). In addition to the Common Criteria consequences, it constrains the Trusted Computing specific use cases to a smaller subset.

It should be noted that the design of future generations of chipsets to be brought to the market intends to mediate DMA transfers by adding controls to DMA transfers at chipset level.

6.4 Common Criteria components

The table below lists the differences between EAL4 and EAL5; Components for EAL5 that are marked “./.” are identical to those in EAL4.

Table 14: Differences between EAL4 and EAL5

Assurance Class	***Component for EAL4***	***Component for EAL5***
ACM: Configuration Management	ACM_AUT.1: Partial automation	./.
	ACM_CAP.4: Generation Support and Acceptance Procedures	./.
	ACM_SCP.2: Problem Tracking CM coverage	ACM_SCP.3: Development tools coverage
ADO: Delivery and Operation	ADO__DEL.2: Detection of Modification	./.

Assurance Class	***Component for EAL4***	***Component for EAL5***
	ADO_IGS.1: Installation, generation, Start-up Procedures	./.
ADV: Development	ADV_FSP.2: Fully defined external interfaces	ADV_FSP.3: Semi-formal Functional Specification
	ADV_HLD.2: Security enforcing HLD	ADV_HLD.3: Semi-formal HLD
	ADV_IMP.1: Subset of the implementation of the TSF	ADV_IMP.2: Implementation of the TSF
	ADV_LLD.1: Descriptive LLD	./.
	ADV_RCR.1: Informal Correspondence Demonstration	ADV_RCR.2: Semi-formal Correspondence demonstration
	ADV_SPM.1: Informal TOE Security Policy Model	ADV_SPM.2: Formal TOE Security Policy Model
		ADV_INT.1: Modularity
AGD: Guidance Documents	AGD_ADM.1: Admin guidance	./.
	AGD_USR.1: User guidance	./.
ALC: Life Cycle Support	ALC_DVS.1: identification of security measures	./.
	ALC_LCD.1: Developer defined Life Cycle Model	ALC_LCD.2: Standardized Life Cycle Model
	ALC_TAT.1: Well-defined development tools	ALC_TAT.2: Compliance with Implementation Standards
ATE: Tests	ATE_COV.2: Analysis of Coverage	./.
	ATE_DPT.1: High Level Design testing	ATE_DPT.2: LLD testing
	ATE_FUN.1: Functional testing	./.
	ATE_IND.1: Independent testing	./.
AVA: Vulnerability Assessment	AVA_MSU.2: Validation of Analysis	./.
	AVA_SOF.1: Strength of Function	./.
	AVA_VLA.2: Independent Vulnerability Analysis	AVA_VLA.3: Moderately resistant
		AVA_CCA.1: Covert Channel Analysis

Comments to Components NOT marked "./." in the Components for EAL5 column: Most of these comments are based on educated assumptions that lack evidence because documentation or a detailed analysis is missing.

ACM_SCP.3: Development tools coverage

It can be assumed that the configuration management in use for the hypervisor also contains the development tools.

ADV_FSP.3: Semi-formal Functional Specification

There is no evidence that a semi-formal function specification exists for Xen, especially when considering the limiting effects on the functionality that the architecture of Xen intrinsically has.

ADV_HLD.3: Semi-formal HLD

No High Level Design documentation is known. A semi-formal HLD is lesser likely.

ADV_IMP.2: Implementation of the TSF

All portions of code that are identified in the (non-existent) Low Level Design documentation must have their interactions identified.

ADV_RCR.2: Semi-formal Correspondence demonstration

Functional Specification (FSP) and High Level Design (HLD) need to be available in semi-formal format. ADV_RCR.2 requires to describe the correspondence determination between them, and between all other informal representations.

ADV_SPM.2: Formal TOE Security Policy Model

The question whether a formal security policy model can be articulated for a Xen hypervisor that claims to separate paravirtualization domains and supply Trusted Computing functionality only needs detailed investigation on behalf of a theoretical methodology researcher. This item is referred to again in the discussion of this document's results.

ADV_INT.1: Modularity

Modularity is not required at EAL4 and below. Same as ADV_SPM.2 above. If Trusted Computing components are present and shall be part of the TOE, a claim for modularity must at least be evidenced here.

ALC_LCD.2: Standardized Life Cycle Model

The business model is likely to determine the Life Cycle management terms for Xen today. ALC_LCD.2 requires that the Life Cycle Management documentation explains why it was chosen. Even though there were security updates for Xen during 2007, it can be safely assumed that the process for these updates does not belong to a more comprehensive process framework.

ALC_TAT.2: Compliance with Implementation Standards

The Tools and Techniques component's objective is to determine the developer's usage of well-defined development tools. Depending on the evaluator's viewpoint, this may involve the evaluation of compilers and their compliance to programming language standards, which, again, imposes direct requirements on the availability of documentation of the compiler and associated tools. The completeness of these documents is uncertain.

ATE_DPT.2: LLD testing

EAL4 mandates testing against interfaces that are defined in the High Level Design, EAL5 against the Low Level Design. Please see Section 2: Documentation and the **first blocking item** mentioned in this section.

AVA_VLA.3: Moderately resistant

Independent vulnerability analysis means that not only the developer has assessed if vulnerabilities are/have been identified in the TOE, but that the evaluator has analysed the TOE for resistance against attacks of medium attack potential. There is no reasonably arguable forecast as to whether the Xen hypervisor would satisfy these conditions or not. Fulfilling these requirements may be subject to sufficient resource allocation in the evaluation process.

AVA_CCA.1: Covert Channel Analysis

On the 32bit architecture, the Xen hypervisor makes use of trapping CPU instructions that flush security relevant descriptor tables. The change of those descriptor tables is granted to the virtualized guest, just not the flushing instruction. This method of defining an additional security level provided by the CPU is near the end of the depth that the CPU specification states. It is one example where the use of corner specification may be a good starting point in a Covert Channel Analysis, and other issues with modern CPUs that need microcode to run is inevitably necessary.

The incapability of the Xen architecture to fulfill one or more of the Common Criteria components at EAL5 denotes the **third blocking item** in the feasibility of a Common Criteria evaluation.

6.5 Security Target properties

This chapter outlines the properties of a Security Target without attempting to actually state it in detail. This approach shall give an overview over the Security Target in a form how it could be outlined, as a result of conclusions and considerations as listed above. Assumptions that concern the deployment environment (such as the hostility of the attached network, or a cooperative user assumption) are omitted and left for closer definition based on the objected workload scenario in a trade-off to the resources required for the evaluation.

For the overview and for the demonstration of the differences between options for EAL4 and for EAL5, items are listed below for both evaluation assurance levels.

Security Target for EAL4:

- Xen hypervisor runs on 32bit or 64bit architecture. The TOE (and the associated TSF) include
    - memory separation between hypervisor and guest domains
    - I/O path providing for dom0 to the hardware
    - I/O path providing for domU guest domains that consume virtualized drivers served by dom0.

- hypercall interface as provided by the hypervisor
- system administrative interfaces (through hypercalls) as exposed to dom0.
- virtual TPM driver with Low Level and High Level interface to hardware and to guests that consume the driver
-

- dom0 acts as the host operating system for the paravirtualization scheme and is therefore part of the TOE. The evaluated configuration of dom0 is desirable to be reduced to the minimum necessary to operate the hypervisor. This may conclude in the absence of networking services and other programs that operate on a privilege boundary.

The certification at EAL4 requires a complete evaluation of the host Operating System that runs in dom0. Vice versa, since such certifications have been successfully completed in the past, the TOE for an EAL4 evaluation may be considered the traditional system like with a natively running Linux kernel, enhanced by a hypervisor, and the Controlled Access Protection Profile may be applied. This moves the scope and the focus of the evaluation, specifically the evaluated TSFs, towards the traditional security policy model of a single layered security general purpose utility computing Operating System, away from a detailed investigation of the separation functions of the hypervisor. This should not be considered a damage due to the possible homogeneous Evaluation Assurance Level in the system.

Please note that as of quarter 4 2007, the CAPP has been withdrawn and is being discontinued. Successor Protection Profiles in the family of Medium Robustness Protection Profiles require functionality that may not be available in the host Operating System.

Security Target for EAL5:

- The Xen hypervisor runs on 32bit or 64bit hardware. The TOE and the associated TSF include (and are mostly limited to):
  - domain separation functions provided by the hypervisor, involving memory management (MMU virtualization) and CPU utilization.
  - the hypercall interfaces provided by the hypervisor, along with the I/O paths for the host Operating System (dom0) and the guest Operating System (dumU).
  - the networking subsystems and routing policy enforcement for networking between guests, if it exists.
  - the virtual TPM driver, if it exists, along with its interfaces to the hardware and its exposed interface to the guests, as well as policy enforcement specifics for access to the virtual TPM by guests, if it exists. (-> persistent storage encryption keys in use by guests to protect their data).
  - the measurement (hash) of images that the hypervisor intends to transfer

control to in the context of a guest, and the storage of the results in the TPM of the system (hardware).

- explicitly excluded from the TOE are
  - dom0
  - dom0 supplied integrity, confidentiality and availability of I/O resources
  - dom0 supplied integrity, confidentiality and availability of networking resources
  - graphics I/O
- DMA through bus systems of the system represents an open question.

6.6 Conclusion, discussion

This document outlines that, while EAL4 evaluation may be possible with some effort of providing information about the TOE in the form of documentation, an EAL5 evaluation is not feasible with the Xen hypervisor. Three major blocking items have been identified:

1) absent documentation
2) DMA data transfers by hardware that is in control of a device driver that is operated by the dom0 host operating system that is not running at the same privilege level like the hypervisor cannot be mediated by the hypervisor. This constraint may disappear with the implementation of chipset design on behalf of CPU and chipset manufacturers.
3) Besides absent documentation that would, if present, allow for the evaluation of individual functional requirements, other design related criteria listed above in the Common Criteria components listing are not met.

An option to overcome some few of the design related modularity and layering weaknesses of paravirtualization was outlined, which implied the exclusion of I/O integrity, confidentiality and availability from the TOE to leave these controls to the guest Operating System to implement. This drastically reduces the TOE complexity and coverage, but comes with the price of reducing the credibility of the evaluated claims and may not even be possible to be conclusively shown. For this reason, this paper concludes that an EAL5 evaluation of the Xen hypervisor cannot be conducted at the present state of the architecture and the available material.

Provided that documentation is written and/or made available to an evaluator, an EAL4 evaluation of the Xen hypervisor is feasible. The TOE for such an evaluation resembles that of a traditional, non-paravirtualized Operating System with functional enhancements. The definition of a Protection Profile that takes paravirtualization design into account is clearly desirable.

Virtualization and paravirtualization currently experience a strong demand in the IT industry. While the idea of virtualization is by far not new to Information Technology, and while the benefits of virtualization technology are mostly focusing on Data Center centric use cases oriented towards reducing operational and investment costs through consolidation and energy saving, additional security is often promoted and marketed. With the conclusion that the Xen hypervisor can be evaluated at maximum the same Evaluation Assurance Level like the host Operating System that runs in dom0, the security benefit clearly does not consist of a higher confidence in the security functions in place at the hypervisor or the Operating System layer! However, the virtualization layer (hypervisor) still adds an additional control to the system by introducing an indirection layer that abstracts the hardware from the Operating System. This additional control is usually the basis for sometimes rather emotional statements about virtualization adding additional security.

As conclusion of the considerations discussed above, it can be seen that reaching Common Criteria Assurance Levels beyond EAL4 intrinsically requires to aim for that goal right from the start, before even the design phase of the development process begins. This wisdom is well-known among security experts, and it basically corresponds to the first most important preferences with regards to the properties of desired IT solutions when probing IT professionals: Security is not among them. Security is often understood to be the absence of security related problems, rather than the presence of properly implemented security controls that may consume (human and monetary) resources when leveraged. This dogma has been applied to the ideas behind Xen, too.

Methodologies for evaluating the security in IT solutions currently neglect sociological and economical considerations of software and of software development methods. Free and Open Source Software (FOSS) has gained momentum in the marketplaces and much trust among its users due to the transparency and the openness of its code, the possibilities to contribute to the development of software and due to the traceability of changes to the software. Since, at least in the medium assurance software world, software security should be considered a process rather than a state, these socio-economic environmental conditions could be taken into account more thoroughly. The definition of a methodology that not only overcomes the weaknesses of Common Criteria, but that also attempts to measure the confidence and trust that stems from rather emotional considerations, is and will probably remain a challenge.

6.7 Abbreviations

CB = Certification Body
OSS = Open Source Software
LLD = Low Level Design
HLD = High Level Design
TOE = Target of Evaluation
TSF = TOE Security Function
ST = Security Target
CM = Configuration Management
CAPP = Controlled Access Protection Profile
ISV = Independent Software Vendor
IHV = Independent Hardware Vendor
CERT = Computer Emergency Response Team

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