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An Intrusion Detection Approach by Global Analysis

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***Abstract*— This paper describes literature works in intrusion detection field. After that, we propose an intrusion detection method in Linux/Unix commands using global analysis. This method was applied to distinct normal user behavior from intruders behavior. The main features of this work are twofold. It exploits formal method in the intrusion detection field. It presents our tool for Linux Intrusion Detection (TLID) which can automatically transform Linux code to Symbolic Model Verifier.**

***Keywords*— Computer attacks, intrusion detection, computer security, Linux commands, model verifier**

I. Introduction

The intrusion field was introduced by Anderson. It was defined as an attempt or a threat to be the potential possibility of a deliberate unauthorized attempt to access information, manipulate information, or render a system unreliable or unusable [1]. The difference between intrusion and attack consists of the fact that intrusion is a malicious, externally or internally induced fault resulting from an attack that has succeeded in exploiting vulnerability, while a fault is the adjudged or hypothesized cause of an error, the cause of which is intended to be avoided or tolerated. An attack is a malicious technical interaction fault aiming to exploit vulnerability as a step towards achieving the final aim of the attacker [2].

A statistical study shows that 98% of enterprises have a firewall to be protected from external attacks; however, 80% of attacks came from internal users [3]. Detecting internal normal user behaviour is a difficult problem because a user can have much dynamic behaviour and it will be almost difficult to create user profiles that determine the normal behaviour. Using a system to distinct normal user from intruders is necessary. This system is called Intrusion Detection System (IDS). It is defined as a security technology attempting to identify and isolate computer systems intrusions [4].

During the last two decades, many strategies and methods for intrusion detection have been developed. We choose to work with Unix/Linux operating system because in people's minds, if it is non-Windows, it is secure [5]. This hypothesis will be countered here. More details for Unix/Linux system can be found in [6]. The literature on detection using Linux/Unix commands offers a variety of methods. Despite their diversity, their common objective is: to distinguish between a normal behaviour and an intrusive behaviour. They are based on local analysis witch can not be equivalent to a global analysis.

The reminder of the paper is organized as follow. Section 2 deals with intrusion background. In section 3, we describe our method. In section 4 we propose the TLID tool, and we show some experimental results for intrusion scenarios. In section 5 we will draw our conclusions and plan for future work.

II. Intrusion Background

The next subsections summarize detection methods using UNIX commands and show their limitations.

A. Detection Using UNIX Commands

The object of intrusion can be files, data bases, network connection, Input/output systems or commands Linux/Unix.

In this paper we are interested about intrusion using Linux/Unix commands because it can characterize user behaviour more efficiently than other object. The followings paragraphs present some works about methods using Unix commands. These works are interested on intrusion detection or on a specific intrusion like masquerade detection.

Ilgun, et al. present the state transition analysis method [7][8]. They used the known Unix intrusion to create a penetration scenario. A penetration is viewed as a sequence of actions performed by an attacker that leads from some initial state on a system to a target compromised state, where a state is a snapshot of the system representing the values of all volatile, semi-permanent and permanent memory locations on the system. The initial state corresponds to the state of the system just prior to the execution of the penetration. The compromised state corresponds to the state resulting from the completion of the penetration. Between the initial and compromised states are one or more intermediate state transitions that an attacker performs to achieve the compromise.

Another method is based on sequence matching. The incoming stream event is segmented into overlapping fixed length sequences. The choice of the sequence length, l, depends on the profiled user. In practical, it's fixed to the value $l = 10$ in the SEA dataset [9]. Each sequence is then treated as an instance in an l-dimensional space and is compared to the known profile. The profile is a set, $\{T\}$, of previously stored instances and comparison is performed between all $y \in \{T\}$ and the test sequence via a similarity measure. Similarity is defined by a measure, Sim(x, y), which makes a point-by-point comparison of two sequences, x and y, counting matches and assigning greater weight to adjacent matches.

The maximum of all similarity values computed forms the score for the test command sequence. Since these scores are very noisy, the most recent 100 scores are averaged. If the average score is below a threshold an alarm is raised. The threshold is determined based on the quantiles of the empirical distribution of average scores [10].

Another method, used statistical method, is called uniqueness. It is based on the idea that commands not previously seen in the training data may indicate an attempted masquerade. Uniquely used commands account for 3% of the data. A command has popularity i if exactly i users use that command. They group the commands such that each group contains only commands with the same popularity. They define a test statistic that builds on the notion of unpopular and uniquely used commands. They assign the same threshold to all users. This threshold is estimated via cross validation: They split the original training data in the SEA dataset into two data sets of 4000 and 1000 commands. Using the larger data set as training data, they assign scores for the smaller one. This is repeated five times, each time assigning scores to a distinct set of 1000 commands. They set the threshold to the 99th percentile of the combined scores across all users and all five cross validations. For their data, the resulting threshold is 0.2319 [9][11].

B. Limitations in existing methods

The intrusion detection method in Linux/Unix commands using formal verification seeks to improve on some of limitations that the authors observed in the existing methods. This section briefly identifies some of their characteristics. The major weakness of these methods is that they depend on aggregative, training or experimental past data. The results of statistical methods are closed to the training data while the result of state transition analysis method is depend with the defined penetrations attacks which are non valuable now.

Another limitation is they are based on analysing command by command (line per line). This local analysis can not be equivalent to a global analysis (all of lines).

Lastly, they cannot make difference between the orders of commands in the sequence used. The statistical methods are based on the command frequency while a state transition analysis method can’t detect the attacks based in frequency such as deny of service.

In the following, we focus in these limitations to present our method based on model using formal verification with Symbolic Model Verifier (SMV).

III. INTRUSION DETECTION IN LINUX/UNIX COMMANDS BY GLOBAL ANALYSIS

This section presents an overview about our intrusion detection method by global analysis. It’s based on temporal logic and formal verification.

The observed user behavior is deduced from Linux terminal. In the rest of this paper, we use the term Linux, which can be interchanged with Unix. We are interested about a Linux script not about a line of commands. So we focus on global analysis, which is represented by a Linux script. Knowing that a global analysis cannot result automatically from local analyses, the fundamental question is: what are the typical properties which characterize an attack script (a sequence of commands leading to faults) ?

The temporal logic seems address this question. So it is necessary to specify the global properties. The observed user behavior is expressed by a Linux / Unix script, and transformed afterward in a target language. It is so necessary to verify, at any time, the respect of the properties. This check, refers to "model checking", was experimented with SMV (Symbolic Model Verifier). This led to LSc2SMV (Linux Script to Symbolic Model Verifier). This prototype/tool allows a Linux code processing to SMV language.

The result will be verified properties if the behaviour is normal or violated properties if the behaviour is intrusive. Figure 1 illustrates this schema.

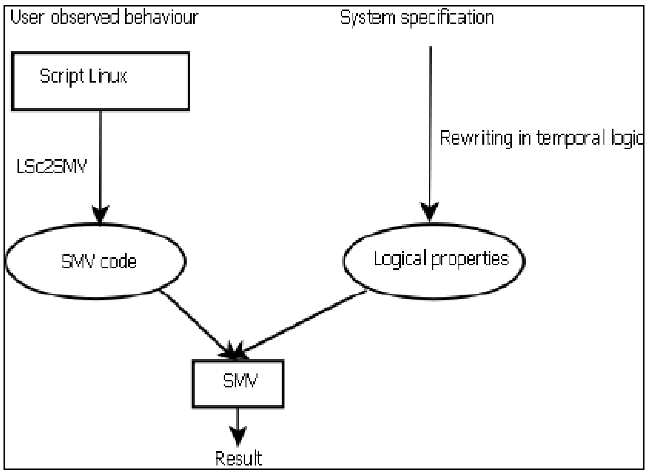

Fig.1 A diagram tracing our method.

A. Global properties

The global properties or anti-properties (AP) are unwanted properties that can cause damage in our system. They can be:

- AP1: Execute some illegal commands,
- AP2: Change source or command destination,
- AP3: Execute illegal actions (parameters, etc.),
- AP4: Having infinite loop,
- AP5: Having auto-replication,
- AP6: Detain a resource infinitely …

The system specification are formalizes using the AP. They can be expressed in proportional logic or temporal logic.

The temporal logic is used within the framework of the reagent systems, which where the software is supposed to maintain a relation of coherence between the input flows and the output flows. The temporal logic allows expressing the state evolution of a system.

We choose the temporal logic because temporal logic is an extension of propositional logic. Either in temporal logic, propositions are qualified in terms of time.

The following paragraph explains how to write some of the anti-properties AP and properties (P) using temporal logic.

AP: Execute some illegal commands

The AP considers that user can execute some illegal commands. For example, if the user is not an administrator, he can't execute some commands like adduser, userdel, crontab, etc.

P: Do not execute some illegal commands;

P = {(Ui,,Cj)/Ui $\in$ U et Cj $\in$ C}

where: U: set of users

C: set of illegal commands

(Ui, Cj): Ui can use Cj

Use(Ui, Cj) $\rightarrow$ (Ui, Cj) $\notin$ P

Some others anti-properties can be formalized such as having auto-replication, detain a resource infinitely, etc. Due to space limitation, others properties can be found in [12].

B. LSc2SMV

The LSc2SMV tool will convert Linux script (LSc) to an SMV language.

A specification for SMV is a collection of properties. Properties are specified in a notation called temporal logic. Temporal logic specifications can be automatically formally verified by a technique called model checking.

SMV is quite effective in automatically verifying properties. Sometimes, when checking properties, the verifier will produce a counterexample. This is a behavioral trace that violates the specified property. The SMV code will be in the form of main module ().

Table I shows the transformation in the condition and loop cases form.

TABLE I
CONDITIONS AND LOOP CASES

Type	LSc	SMV
Condition	if[<condition>] <stmt1> else <stmt2> fi	if(<condition>) <stmt1> else <stmt2>
Case	case $variable in val1) stmt1> ; ; ...... *) <stmtn> ; ; esac	case{<cond1> : <stmt1> ... <condn> : <stmtn> [default : <dftlstmt>]}
Switch	switch(<expr>) <case1> : <stmt1> breaksw <casen> : <stmtn> breaksw default : <dftlstmt> breaksw endsw	switch(<expr>){ <case1> : <stmt1> ... <casen> : <stmtn> [default : <dftlstmt>]}
for	for var in $files ; do	for(var = init ; cond ; var = next) <stmt>
while	while condition ; do <stmt> done	-

The indirect transformation is based on properties to verify in Linux script.

Some other conversion in the file name or in the folder name, in arrays, in expressions cases, in functions … can be given. More details can be found in [12].

C. Observed Behavior Analysis

Algorithm in figure 2 gives the user behavior type. The output of this algorithm is the behavior type. There are two inputs: Φ, the anti-properties, and β, the observed's user behavior.

```
Input: $\beta$ and $\Phi$
Output: Behavior type
1 begin
2     if $\beta$ satisfied AP then
3         Forbid $\beta$
4     else
5         Authorized behavior
6     end
7 end
```

Fig.2 Algorithm for analyzing the observed behavior

In anomaly detection of user behavior, we need to distinguish between normal and intrusive behavior. So we analyze the observed user behavior.

The basic action of anomaly detection is to compare the observed user behavior and the anti-properties. Two cases appear in the algorithm:

1) The observed user behavior satisfied one or many anti-properties.

2) The observed user behavior doesn't satisfy any anti-properties.

The first case represents the intrusive behavior. The second case represents the normal behavior. In fact the user script typed is an authorized script.

Let's: β the observed user behavior

φ an anti-property

Φ a set of anti-properties

$\beta \models \Phi$: the observed user behaviour satisfy all defined anti-properties

$\beta \models \varphi$ *:* the observed user behaviour satisfy a anti-property; In this case, we should verify the other properties because we can have :

- $\beta \not\models \Phi$: the observed user behaviour don't satisfy all defined anti-properties. The observed user behaviour is an authorized behaviour.
- $\beta \models \Phi$: the observed user behaviour satisfy all defined anti-properties. The observed user behaviour is an intrusive behavior.

IV. TLID: TOOL FOR LINUX INTRUSION DETECTION

The TLID architecture can survey a user and analyze his behaviour. TLID can do a global analysis between users.

A. Survey a user

There are two solutions to survey a user:

- The first solution consists in using the file .bash_history. But this file cannot give a strengthened and real-time history because when you use other shell, like csh,, this method cannot save the history. Either when you tape kill -9.
- The second solution is to develop a patch. It consists to modify file system in Linux, which are bashhist.c, histexpand.c, histfile.c, history.h and history.c. We do this because Linux is an open source (to obtain the patch e-mail : bentekaya.ines@voila.fr).

You can choose a user and we obtain the user’s observed behaviour. You can either choose a user and a day, shown in figure 3, and we obtain the user’s observed behaviour in this day. The result is composed by time, process identifier (PID) and commands.

B. Analyse user behaviour

After survey a user, you can choose a property to verify. In this example, we choose to verify the service deny in figure 4. The button LSc2SMV became enabling. When we click below, we obtain the SMV file. This file contains the verification of every actions do by selected user in the chosen day. It consists to verify the specified properties. We choose ``Prop|Verify all'' to verify if the properties we specified in fact hold true or false for all time. If the property should be false, a counterexample appears in the trace page.

Intrusion scenario Sc between users can be defined as:

Sc = {A, V, S} with:

A: an attacker

V: a victim

S = {s1, s2… sn}: a set of steps

Every step is a sequence of commands with their parameters. The next paragraph shows an example of scenario. It have been developed and tested in Linux Red Hat Enterprise version 5 and we use TLID and SMV for verification.

We develop an example of denial of service which is a fork bomb. The code in figure 3 is the following:

```
[ines@localhost tmp]$ function testb()
{
testb|testb &
} ;testb
```

It works by creating a large number of processes very quickly in order to saturate the available space in the list of processes kept by the computer's operating system. If the process table becomes saturated, no new programs may start until another process terminates.

The generated SMV code is given by figure 4. The properties to verify is called deny. We choose ``Prop|Verify all'' to verify deny. The result is given by figure 5. We have a violated property (false value) because the behaviour is intrusive.

Another scenario consists of sending many mail from user ines to another user to saturate his mail. In this case, the user troismille cannot access to his e-mail. The scenario is given by figure 6.

Using TLID, we choose the anti property: Having infinite loop. If we don’t know how a property to choose, we can mark all checkbox. The result is given by figure 7. The behaviour is intrusive.

V. Conclusions

In this paper, we are interested by attacks using Linux commands. We have proposed a new method for anomaly detection of user behavior. It exploits model checking to verify the correctness of our system. It combines security field with formal verification. This method is applied to distinct normal user behavior from intruders’ behavior.

The user’s observed behaviour is deduced from Linux terminal. We are interested about a Linux script not about a line of commands to perform a global analysis. Knowing that a global analysis cannot result automatically from local analyses, the fundamental question is: what are the typical anti-properties which characterize an attack script?

We choose to transform these properties into temporal logic. We exploit model-checking to automatically verify if a given user behaviour satisfy or not some properties. This led to the TLID tool development. We give some experimental results.

There is another attacks group which can be named unknown attacks. In this new group, attacks could cause the intrusion detection systems crash and thus incomplete testing. It becomes clear that present approaches to evaluate intrusion detection system are limited to some known attacks.

We divide our future work into two main parts: refine and improve attacker competence and extend scenario to include multi-attacks and equivalent attacks.

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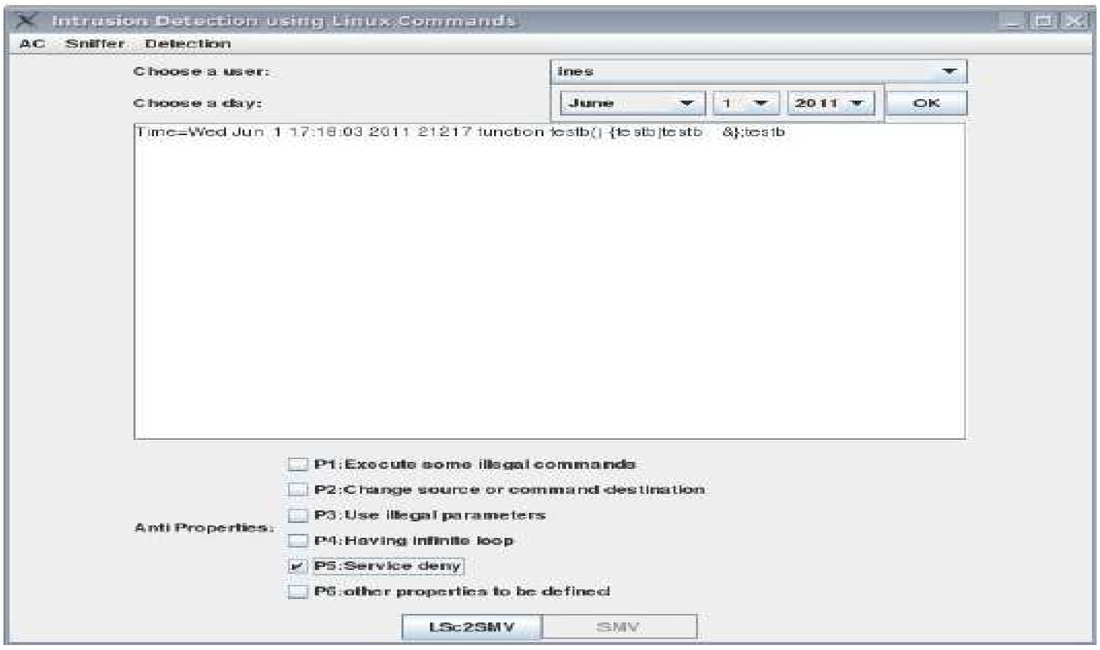


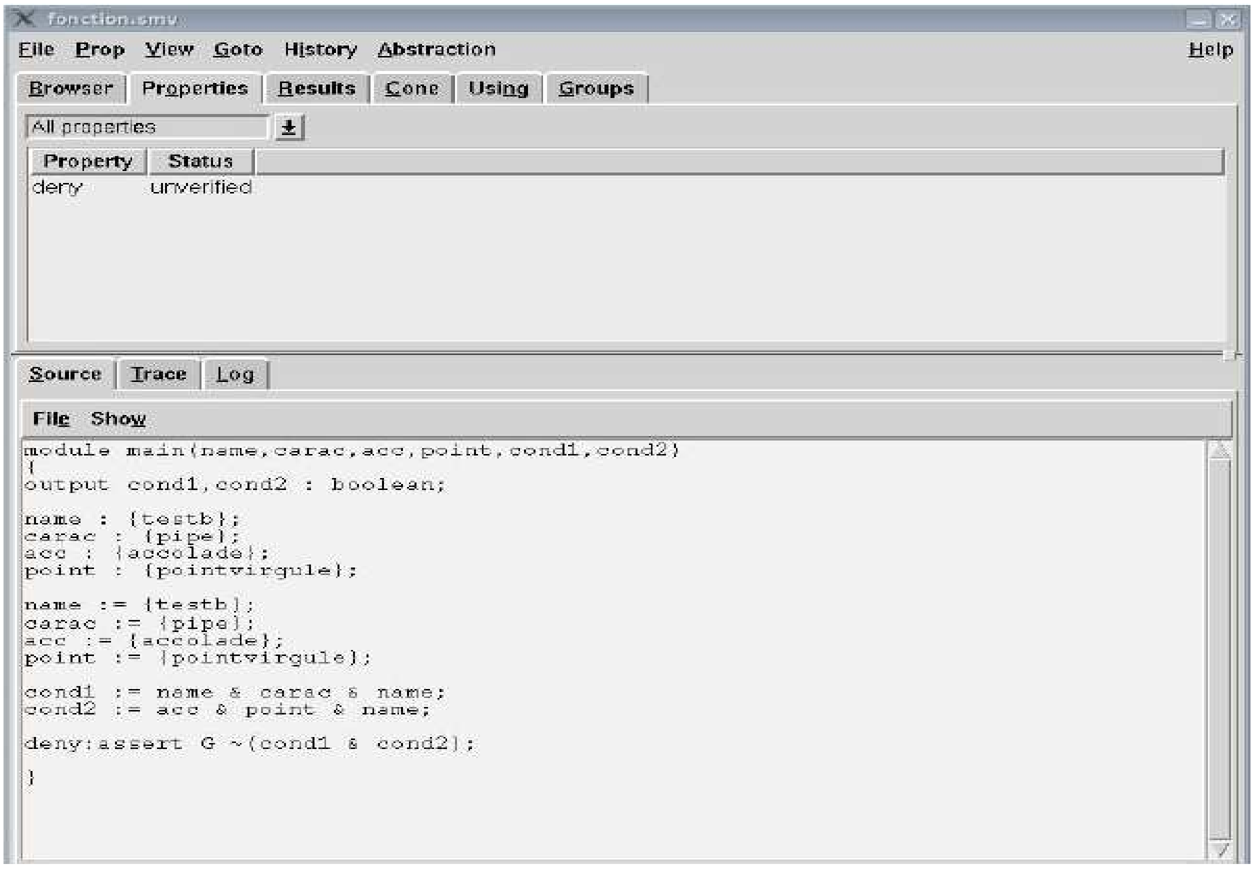
Choose a user: ines

Choose a day: June 1 2011

```
Time=Wed Jun 1 17:18:03 2011 21217 function testb() {testb|testb &};testb
```

Anti Properties:
- [ ] P1:Execute some illegal commands
- [ ] P2:Change source or command destination
- [ ] P3:Use illegal parameters
- [ ] P4:Having infinite loop
- [✓] P5:Service deny
- [ ] P6:other properties to be defined

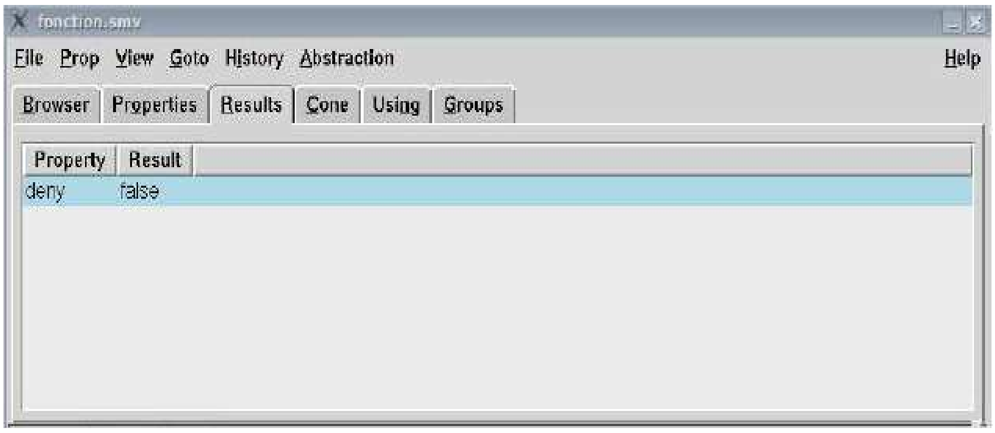
Fig.3 User’s observed behaviour in a chosen day



Property	Status
deny	unverified

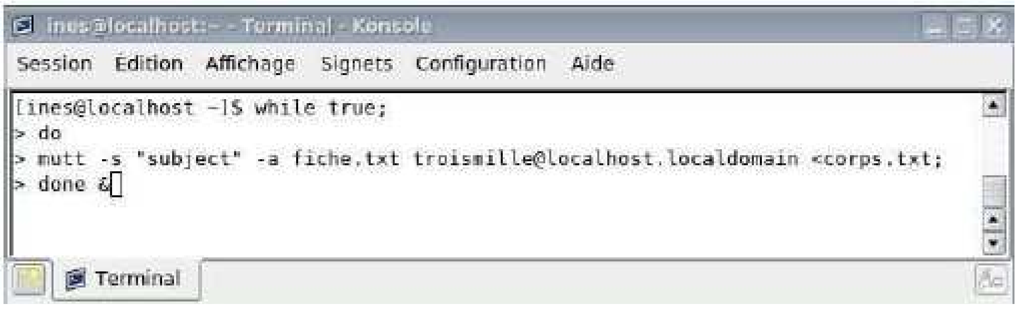
```
module main(name,carac,acc,point,cond1,cond2)
{
output cond1,cond2 : boolean;

name : {testb};
carac : {pipe};
acc : {accolade};
point : {pointvirgule};

name := {testb};
carac := {pipe};
acc := {accolade};
point := {pointvirgule};

cond1 := name & carac & name;
cond2 := acc & point & name;

deny:assert G ~(cond1 & cond2);

}
```

Fig.4 The generated SMV code


fonction.smv
File Prop View Goto History Abstraction Help
Browser Properties Results Cone Using Groups

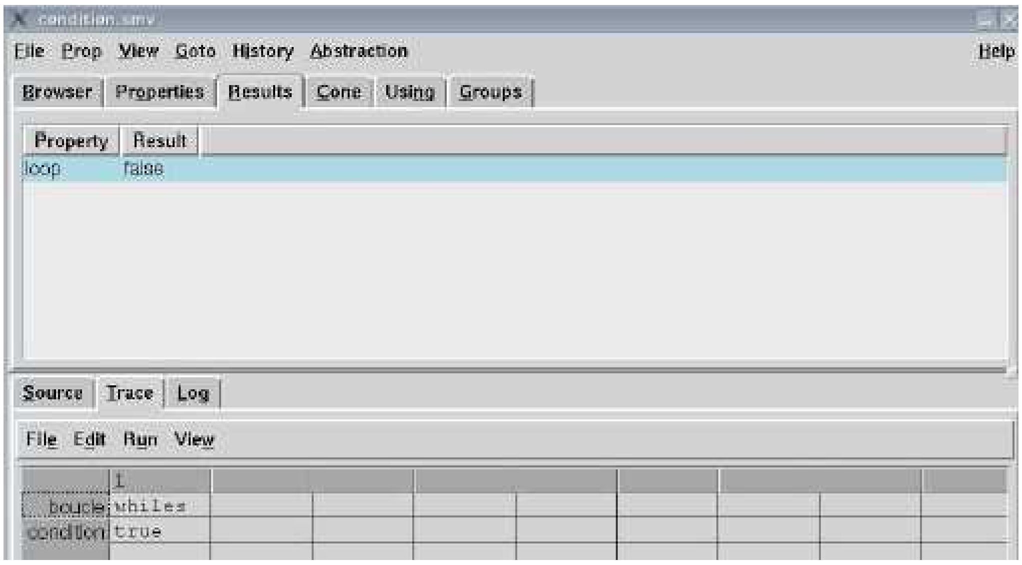
Property	Result
deny	false

Fig.5 Verification result


ines@localhost:~ - Terminal - Konsole
Session Edition Affichage Signets Configuration Aide
Terminal

```
[ines@localhost ~]$ while true;
> do
> mutt -s "subject" -a fiche.txt troismille@localhost.localdomain <corps.txt;
> done &
```

Fig.6 An example of having infinite loop scenario


condition.smv
File Prop View Goto History Abstraction Help
Browser Properties Results Cone Using Groups
Source Trace Log
File Edit Run View

Property	Result
loop	false

	1
boucle	whiles
condition	true

Fig.7 The result of having infinite loop scenario

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