#### **MONID**

A Temporal Logic Based Framework for Intrusion Detection

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September 2023



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#### **Intrusion Detection**



Intrusion detection means maintaining constant surveillance on a system in order to detect any misuse of these weak areas as soon as feasible so that they can be repaired.

#### There are three approaches:

- signature-based: aims to identify patterns and match them with known signs of intrusions;
- anomaly-based: can identify new attacks when it detects behavior that differs significantly from previously learned normal behavior;
- hybrid: combines the best of both worlds by looking at patterns and one-off events.

We will present MONID which is a signature-based intrusion detector.

#### What is MONID? I



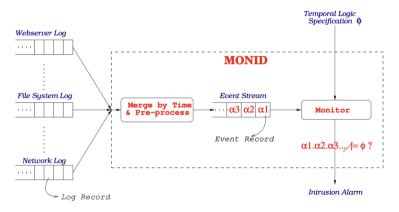
MONID is a prototype which can detect intrusions on a system and operates in both online and offline modes.

#### In order:

- 1. we will use the logic **EAGLE** to define intrusion patterns using temporal logic formula  $\varphi$ ; in this case the monitored formula will be  $\psi = \Box(\neg \varphi)$ .
- 2. MONID will create a stream of events  $\sigma=\alpha_1,\alpha_2,\ldots$  obtained from a merge of the logs by ascending time order;
- 3. a monitor will processes each event  $\alpha_i$  as it happens and updates the monitored formula  $\psi$  to store a relevant summary;
- **4**. an intrusion alarm is triggered if, for any reason,  $\alpha_1, \alpha_2 \dots \not\models \psi$ .

#### What is MONID? II

The architecture is the following.



# **Assumptions**



Two assumptions must be made:

1. There is a finite sequence of events called  $\sigma = \alpha_1, \dots, \alpha_n$  that is a merge of the system registered logs organized by ascending time. The structure of an event record  $\alpha_i$  is the following:

```
{\tt LoginLogoutEvent}\{userId: \underline{\mathsf{string}},\ action: \underline{\mathsf{int}},\ time: \underline{\mathsf{double}}\}
```

An example of event could be:

```
\{userId: "Lori", action: login, time: 20\}
```

2. For each attack, there is a formula  $\psi$  which specifies the absence of it.

Now let us start on the basics of EAGLE.



# EAGLE, a Temporal Monitoring Logic

#### **Basics I**

EAGLE offers a succinct but powerful set of primitives, supporting recursive parameterized equations with a minimal/maximal fix-point semantics together with three temporal operators: next-time ( $\bigcirc$ ), previous-time ( $\bigcirc$ ), and concatenation ( $\cdot$ ).

As a result, rules in EAGLE give us the power to create specific temporal operators as well as to bind and modify data. This property turns out to be crucial for succinctly expressing executions of attack-safe systems. EAGLE

operates with *finite trace* semantics, meaning it checks formula satisfaction only at the end of a trace. However, in intrusion detection where event sequences can be infinite, the goal is to trigger an alarm as soon as a property is violated, thus MONID continuously checks the formula's satisfaction status after each event.

#### **Basics II**

Let us start with an example.

#### **Example 1**

We want to express the property "Whenever there is a login by any user x, then eventually the user x logs out". In EAGLE we can do it with the following rules:

```
\underline{\min} \ \mathtt{EvLogout}(\underline{\mathit{string}} \ k) = (action = \mathtt{logout} \land userId = k) \lor \bigcirc \mathtt{EvLogout}(k) \\ \underline{mon} \ M_2 = ((action = \mathtt{login}) \to \mathtt{EvLogout}(userId))
```

Once the rules are created, the monitor will evaluate and update the monitored formula  $M_2$ . A possibile trace  $\sigma=\alpha_1,\alpha_2$ , where:

```
\alpha_1 = \{userId : "Lori", action : login, time : 17.0\}
\alpha_2 = \{userId : "Lori", action : logout, time : 150.0\}
satisfies M_2.
```

# Syntax I

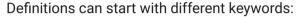


Each specification S is made up of an observer part O and a declaration part D.

$$\begin{split} S &::= D \, O \\ D &::= R^* \\ O &::= M^* \\ R &::= \{ \underbrace{\mathsf{max} \mid \mathsf{min} \}} \, N(T_1 \, x_1, \dots, T_n \, x_n) = F \\ M &::= \underbrace{\mathsf{mon}} \, N = F \\ T &::= \underbrace{\mathsf{Form}} \mid \mathsf{primitive} \; \mathsf{type} \\ F &::= \mathsf{expression} \mid \underline{\mathsf{true}} \mid \underline{\mathsf{false}} \mid \neg F \mid F_1 \wedge F_2 \mid F_1 \vee F_2 \mid F_1 \wedge F_2 \mid F_2 \wedge F_2 \wedge F_2 \mid F_$$

Let us focus on some details.

# Syntax II



- mon: specifies the EAGLE formulas to be monitored and cannot have a recursive definition; as already told, these kind of rules will evolve as new events appear.
- <u>max</u>: defines safety properties (nothing bad ever happens) and have a maximal interpretation.
- <u>min</u>: defines *liveness properties* (something good eventually happens) and have a minimal interpretation.

#### Note.

The difference between maximal and minimal interpretation becomes important only when we are evaluating the at the boundaries of a trace; <u>max</u> rules evaluates at <u>true</u> at initial and final istants, while <u>min</u> rules evaluates at <u>false</u>.

#### **Semantics I**

The semantics of the logic is defined in terms of the satisfaction relation  $\models$  which defines whether a finite execution trace  $\sigma$  satisfies the specification  $\varphi = D \, O$ .

Given a trace  $\sigma$  and a specification D O, satisfaction is defined as follows:

$$\sigma \models DO \text{ iff } \forall (\underline{\mathsf{mon}}\ N = F) \in O.\ \sigma, 1 \models_D F$$

In other words, a trace satisfies a specification if it fulfills each monitored formula (mon) when monitoring from position 1, which is the initial state.

In the following slide we will present the definition of the satisfaction relation  $\models_D \subseteq (Trace \times \mathbb{N}) \times \underline{\mathsf{Form}}$  for a set of rule definitions D.

#### **Semantics II**

```
\sigma, i \models_D expression \text{ iff } 1 \leq i \leq |\sigma| \text{ and } evaluate(expression, \sigma(i)) = true
\sigma, i \models_D \text{true}
\sigma, i \not\models_D false
\sigma, i \models_D \neg F iff \sigma, i \not\models_D F
\sigma, i \models_D F_1 \land F_2 iff \sigma, i \models_D F_1 and \sigma, i \models_D F_2
\sigma, i \models_D F_1 \vee F_2 iff \sigma, i \models_D F_1 or \sigma, i \models_D F_2
\sigma, i \models_D F_1 \to F_2 iff \sigma, i \models_D F_1 implies \sigma, i \models_D F_2
\sigma, i \models_D \bigcap F iff i \leq |\sigma| and \sigma, i+1 \models_D F
\sigma, i \models_D \odot F iff 1 < i and \sigma, i - 1 \models_D F
                             iff \exists i \text{ s.t. } i < j < |\sigma| + 1 \text{ and } \sigma^{[1,j-1]}, i \models_D F_1 \text{ and } \sigma^{[j,|\sigma|]}, 1 \models_D F_2
\sigma, i \models_D F_1 \cdot F_2
                                                     \sigma, i \models_D F[\overline{f} \mapsto \overline{F}, \overline{p} \mapsto evaluate(\overline{P}, \sigma(i))]
                                                  where (N(\overline{\overline{\text{Form}}}\ \overline{f}, T\ p) = F) \in D
\sigma, i \models_{\mathcal{D}} N(\overline{F}, \overline{P})
                                                  otherwise, if i = 0 or i = |\sigma| + 1 then:
                                                      rule N is defined as max in D
```



# **Evaluation algorithm I**

As we can see, a function called evaluate emerges; there are additional functions as well. Let us list them.

- *evaluate* : Form × State. This function is used to evolve at every event the monitored formulas.
- $update : \underline{Form} \times \underline{State} \to \underline{Form}$ . This function is used by evaluate to pre-evaluate a formula if it is guarded by the previous operator  $\odot$
- $value : \underline{\mathsf{Form}} \to \{\underline{\mathsf{true}}, \underline{\mathsf{false}}\}$ . This function returns true if and only if  $\sigma, |\sigma| + 1 \models F$  (or  $\sigma, 0 \models F$ ), and returns false otherwise.

#### Note.

Formally, a formula  $F'=evaluate(F,\alpha_i)$  is created when a formula F is evaluated at an event  $\alpha_i=\sigma(i)$  and has the condition that  $\sigma,i\models F$  if and only if  $\sigma,i+1\models F'$ . With F being the evolved formula, we compute the boolean function value(F) at the conclusion of the trace.



## **Evaluation algorithm II**



More details are in the paper; let us introduce an example.

#### **Example 2**

Given the following rules

```
max \ Always(Form \ F) = F \land \bigcirc Always(F)
  min \; \text{EvTimedLogout}(string \; k, double \; t, double \; \delta) = (time - t < \delta)
             \land ((action = logout \land userId = k) \lor \bigcirc EvTimedLogout(k, t, \delta))
  mon\ M_3 = Always((action = login) \rightarrow EvTimedLogout(userId, time, 100))
and a trace \sigma = \alpha_1, \alpha_2, where
  \alpha_1 = \{userId : "Lori", action : login, time : 17.0\}
  \alpha_2 = \{userId : "Lori", action : logout, time : 150.0\}.
M_3 gets modified, at first step, in
  evaluate(M_3, \alpha_1) = \text{EvTimedLogout("Lori", 17.0, 100)}
             \land Always((action = login) \rightarrow EvTimedLogout(userId, time, 100)).
```

## Relationship with LTL+P

We can define both **Future Time LTL** and **Past Time LTL** operators. As example, let us show the future ones.

$$\begin{array}{l} \underline{\min} \ \mathrm{Next}(\underline{\mathsf{Form}} \ F) = \bigcirc F \\ \underline{\max} \ \mathrm{Always}(\underline{\mathsf{Form}} \ F) = F \land \bigcirc \mathtt{Always}(F) \\ \underline{\min} \ \mathrm{Eventually}(\underline{\mathsf{Form}} \ F) = F \lor \bigcirc \mathrm{Eventually}(F) \\ \underline{\min} \ \mathrm{Until}(\underline{\mathsf{Form}} \ F_1, \underline{\mathsf{Form}} \ F_2) = F_2 \lor (F_1 \land \bigcirc \mathtt{Until}(F_1, F_2)) \end{array}$$

By combining the definitions for the future and past time LTL as defined above, we obtain a temporal logic over the future, present and past, in which one can freely intermix the future and past time modalities; thus, we can state that EAGLE is expressive at least as LTL+P.



# **Conclusions**

# **Conclusions**



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# Thanks for the attention