

Time Dependent Analysis with Dynamic Counter Measure Trees

Rajesh Kumar Dennis Guck Mariëlle Stoelinga

Formal Methods and Tools
University of Twente
Enschede, Netherlands

{r.kumar,d.guck,m.i.a.stoelinga}@utwente.nl

The success of a security attack crucially depends on time: the more time available to the attacker, the higher the probability of a successful attack. Formalisms such as Reliability block diagrams, Reliability graphs and Attack Countermeasure trees provide quantitative information about attack scenarios, but they are provably insufficient to model dependent actions which involve costs, skills, and time. In this presentation, we extend the Attack Countermeasure trees with a notion of time; inspired by the fact that there is a strong correlation between the amount of resources in which the attacker invests (in this case time) and probability that an attacker succeeds. This allows for an effective selection of countermeasures and rank them according to their resource consumption in terms of costs/skills of installing them and effectiveness in preventing an attack.

1 Introduction

Attack trees [12] and its variants [5] are simple yet powerful formalisms to quantitatively express the attack scenarios in a straight forward way. They have been studied extensively in the fields of risk assessment [9], e-voting [7], critical infrastructures [3] and socio-technical security [10]. Based on temporal attributes of the leaf nodes, Attack trees can be further classified as static or dynamic, both of which can be further refined to take into only single parameters [6] [4] or multi parameters [8]. Static analysis techniques are useful in providing answers such as “Given an attacker skill set and attempt, what is the probability of attacker to succeed?” whereas dynamic analysis techniques can answer questions such as “What is probability that an attacker succeeds with Probability of 0.8 in certain t units?”. They can further be refined by adding defence trees [2] or countermeasure trees [11] where both attacker and defender try to restrict the chances of success of each other.

This presentation involves Dynamic Attack Countermeasure trees (ACTs) which are dynamic attack trees enriched with countermeasures. In this presentation we will focus on the inclusion of countermeasures in dynamic ACTs with AND and OR gates. Further, we evaluate the case study as provided in [11] using the ADT toolbox [6] as well as ATCalc, an extension of [1]. As first step we compute the static probabilities by a single parameter bottom up analysis and then extend the model by defining the temporal attributes of the basic attack steps (BAS) to investigate how the attack proceeds over time.

2 Dynamic Attack Countermeasure Trees

An Attack Countermeasure tree (ACT) can be seen as a directed acyclic graph. We formally represent an ACT as a tuple (G, r, L) where:

- G is a directed acyclic graph, i.e $G = (V, E)$ with V a set of all vertices and E a set of all edges such that $E = \{(v, v') \mid \exists v \in V. v' \in \text{children}(v)\}$.

- $r \in V$ is the single top root of (V, E) . It represents the attacker's goal.
- $L : V \rightarrow \Sigma$ is a labelling function that assigns to each vertex an AT element, i.e $\Sigma = (\text{Gates} \cup \text{Leafs})$ where $\text{Gates} = \{AND, OR\}$ is a set of logical gates such that for all $L(v) \in \text{Gates}$, $children(v) \neq \emptyset$ and $\text{Leafs} = A_j \cup D_m \cup M_k$ is a set of basic events such that for all $L(v) \in \text{Leafs}$, $children(v) = \emptyset$ where: (a) A_j is the set of j attack events; (b) D_m is the set of m detection events; (c) M_k is the set of k mitigation events.

To have a time dependent analysis of ACTs, we need to annotate the leaf nodes with two parameters: (1) The probability of a successful execution of an attack step; (2) A random variable X that describes the execution of an attack with respect to time. Due to the memoryless property of exponential distributions, we define the CDF of the random variable X by:

$$P[X < t] = 1 - e^{-\lambda t}.$$

The eventual probability of success obtained in step (1) can be used to compute the parameter $\lambda = \frac{-\ln(1-p)}{t}$ which defines the timed behaviour of an attacker. Note that since any CDF always approaches 1 by increasing the time bound t , this implies that an attacker always succeeds if he is given a sufficient amount time.

2.1 Semantics of BAS and Gates

Basic Attack Step (BAS): A BAS is a basic step of an attacker or defender which interacts with a gate. It is activated once it receives an *activation* signal from its parent node. After an exponential delay with rate λ the BAS propagates a *success* signal to its parent. Note, that the initial *activation* signal is sent by the top-level node at system start.

AND: An AND gate is a conjunction of events. Once it is activated by receiving an activation signal from its parent, it activates its children from left to right. The gate sends out a success signal if all of its attached children are successful.

OR: An OR gate is a disjunction of events. The activation is equal to the AND gate. The gate sends out a success signal if any of its attached children is successful.

Countermeasures: Countermeasures are used to model the defender actions which are used to block associated attack steps. They consist out of two basic events, i.e. *detection* and *mitigation*. The countermeasure is activated on receiving the activation signal from the top node. Once it receives the activation signal it activates only the detection event. After the detection event is successful after an exponential delay by rate λ_1 , the countermeasure gate activates the mitigation event which in turn is successful after an exponential delay by rate λ_2 . A countermeasure gate can be seen from either defender or attacker perspective. From the defender perspective, a countermeasure gate is successful if both detection and mitigation events are successful consecutively. An attacker is interested in an undetected and unmitigated event and his motive is successful if the countermeasure gate fails.

3 Case Study and Interpretation of Results

Malicious Insider attack The ACT for the malicious insider attack (MIA) from [11] is depicted in Figure 1. The MIA ACT has BAS as well as detection and mitigation events. The countermeasure gates are represented by triangles. We conducted our case study by using the ADT toolbox [6] to compare the results to [11] and ATCalc [1] to compute the attack probability over time.

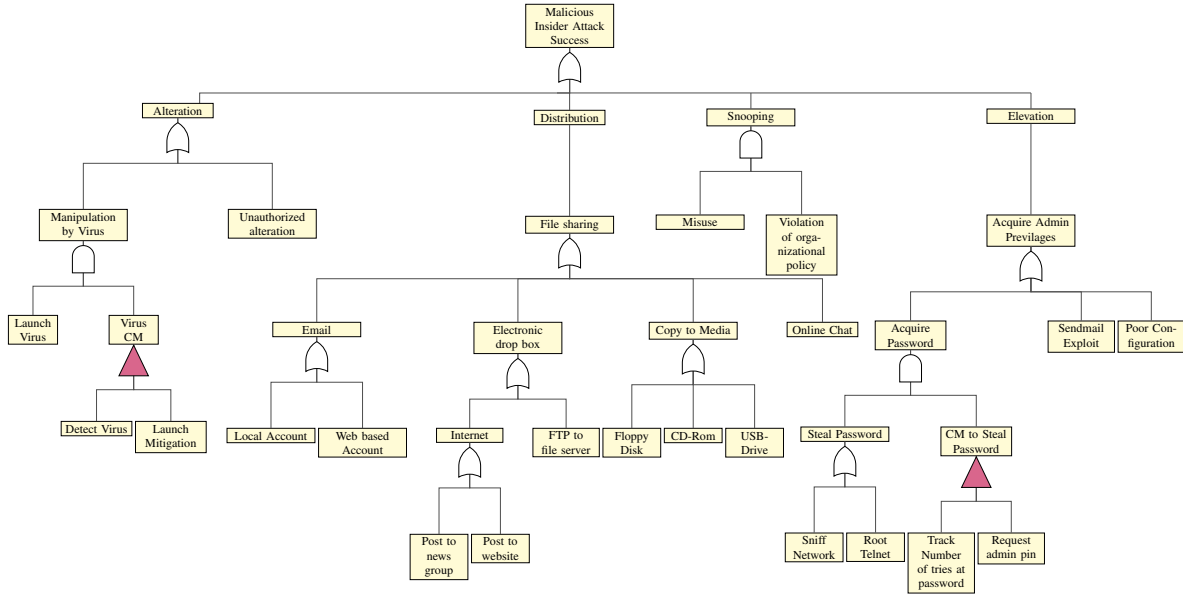
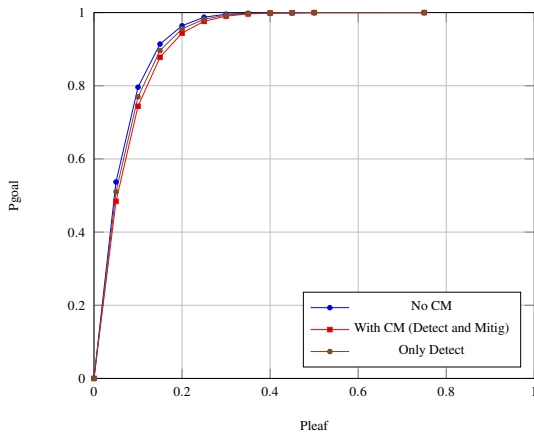
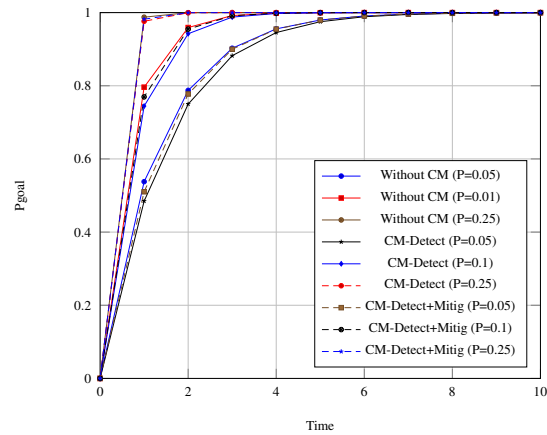


Figure 1: ACT of the malicious insider attack.

The result in Figure 2a is obtained by varying all the probabilities of an attack in the leaf nodes (P_{leaf}) in the range of $[0, 1]$. Figure 2a shows that with the countermeasures being in place, the probability of an attack at the root node (P_{goal}) first decreases with only detection measures (perfect mitigation) and then increases with detection and mitigation measures in place (imperfect mitigation). Those results are equal to the results obtained in [11]. To extend the case study, we consider now the probability of an attack over a time frame of 10 hours. Figure 2b is obtained with different values for P_{leaf} , fixed at $[0.05, 0.1, 0.25]$. The results obtained in Figure 2b shows that given an attacker ample time, it is sure that he will eventually be able to reach the goal. Further, it is nicely observable how much more time an attacker needs to reach his attack goal when the detection and mitigation is in place.

(a) P_{goal} versus P_{leaf} (b) P_{goal} versus TimeFigure 2: P_{goal} versus (a) P_{leaf} (b) Time(sec)

4 Conclusion

We presented the inclusion of time in Attack Countermeasure trees and provided a case study to show the applicability of this approach. This enables us to answer questions like: What is the probability for an attacker to succeed given ' t ' time units by integrating new countermeasures? In future work we consider shared attack scenarios as well as extend the dynamic ACTs with: (1) Sequential AND and Sequential OR gates which can model the casual dependencies of attack steps, i.e. an attack can only take place if attack steps are executed in a certain order; (2) Probabilistic gates which activates the BAS and countermeasure events with discrete probabilities, i.e. attacks as well as countermeasures are only executed with a certain probability.

References

- [1] F. Arnold, A.F.E. Belinfante, F.I. van der Berg, D. Guck & M.I.A. Stoelinga (2013): *DFTCalc: A Tool for Efficient Fault Tree Analysis*. In: *Proc. of the 32nd Int. Conf. on Computer Safety, Reliability, and Security SAFECOMP*, pp. 293–301, doi:10.1007/978-3-642-40793-2_27.
- [2] S. Bistarelli, F. Fioravanti, P. Peretti & F. Santini (2012): *Evaluation of complex security scenarios using defense trees and economic indexes*. *J. Exp. Theor. Artif. Intell.* 24(2), pp. 161–192, doi:10.1080/13623079.2011.587206.
- [3] E. Byres (2013): *The air gap: SCADA's enduring security myth*. *Commun. ACM* 56(8), pp. 29–31, doi:10.1145/2492007.2492018.
- [4] B. Kordy, S. Mauw & P. Schweitzer (2012): *Quantitative Questions on Attack-Defense Trees*. CoRR abs/1210.8092. Available at <http://arxiv.org/abs/1210.8092>.
- [5] B. Kordy, L. Pietre-Cambacedes & P. Schweitzer (2013): *DAG-Based Attack and Defense Modeling: Don't Miss the Forest for the Attack Trees*. CoRR abs/1303.7397. Available at <http://arxiv.org/abs/1303.7397>.
- [6] Barbara Kordy, Piotr Kordy, Sjouke Mauw & Patrick Schweitzer (2013): *ADTool: Security Analysis with Attack-Defense Trees*. In: *Quantitative Evaluation of Systems - 10th International Conference, QEST 2013, Buenos Aires, Argentina, August 27-30, 2013. Proceedings*, pp. 173–176, doi:10.1007/978-3-642-40196-1_15.
- [7] E. Lazarus, D.L. Dill & J. Epstein (2011): *Applying a Reusable Election Threat Model at the County Level*. In: *Electronic Voting Technology Workshop / Workshop on Trustworthy Elections EVT/WOTE*, pp. 12–12. Available at <http://dl.acm.org/citation.cfm?id=2028012.2028024>.
- [8] A. Lenin & A. Buldas (2014): *Limiting Adversarial Budget in Quantitative Security Assessment*. In: *Proc. of the 5th Int. Conf. on Decision and Game Theory for Security (GameSec)*, pp. 155–174, doi:10.1007/978-3-319-12601-2_9.
- [9] S. Paul & R.I. Vignon-Davillier (2014): *Unifying traditional risk assessment approaches with attack trees*. *J. Inf. Sec. Appl.* 19(3), pp. 165–181, doi:10.1016/j.jisa.2014.03.006.
- [10] K. Reddy, H.S. Venter, M.S. Olivier & I. Currie (2008): *Towards Privacy Taxonomy-Based Attack Tree Analysis for the Protection of Consumer Information Privacy*. In: *Proc of the 6th Annual Conf. on Privacy, Security and Trust (PST)*, pp. 56–64, doi:10.1109/PST.2008.18.
- [11] Arpan Roy, Dong Seong Kim & Kishor S. Trivedi (2012): *Attack countermeasure trees (ACT): towards unifying the constructs of attack and defense trees*. *Security and Communication Networks*, pp. 929–943, doi:10.1002/sec.299. Available at <http://dx.doi.org/10.1002/sec.299>.
- [12] B. Schneier (2008): *Schneier on security*. Wiley.