The THREAT-ARREST Cyber Range Platform

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***Abstract*—Emerging technologies are facilitating our daily activities and drive the digital transformation. The Internet of Things (IoT) and 5G communications will provide a wide range of new applications and business opportunities, but with a wide and quite complex attack surface. Several users are not aware of the underlying threats and most of them do not possess the knowledge to set and operate the various digital assets securely. Therefore, cyber security training is becoming mandatory both for simple users and security experts. Cyber ranges constitute an advance training technique where trainees gain hands-on experiences on a safe virtual environment, which can be a realistic digital twin of an actual system. This paper presents the cyber ranges platform THREAT-ARREST. Its design is fully model-driven and offers all modern training features (i.e. emulation, simulation, serious games, and fabricated data). The platform has been evaluated under the smart energy, intelligent transportation, and healthcare domains.**

Keywords—security training, cyber range, security assurance, learning path, security assessment, smart energy, smart shipping, healthcare

I. INTRODUCTION

The evolution of the Information and Communications Technology (ICT) has created a new technological landscape [1]-[2], exploiting among others high-performance computing, 5G communications, advance machine learning (ML) and artificial intelligence (AI), augmented and virtual realities (AR and VR), Big Data analytics, social networking, mobility, and the Internet of Things (IoT).

The increased systems' interactions and complexity leave fruitful space for the currently known security vulnerabilities to survive and expand, as well as for new threats to emerge [3]. The market demand for skillful professionals is expected to grow drastically, and security awareness and training programmes are going to become a necessity, both for individuals and organizations.

Cyber ranges (CRs) form a special method of cyber security training and is considered as a promising solution for the educational needs of this digital era [4]-[5]. Apart from the traditional in-class or on-line educational means (e.g. lectures, tutorials, reading material, etc.), with CRs the learner has the opportunity to gain hands-on experience on setting, defending, or even attacking a system by practicing on a legal, safe, and virtual environment. The trainer creates a virtual lab which may resemble an actually operational system or subsystem. There, the trainee can learn how to administrate mainstream and/or advanced security mechanisms, try different configurations and settings, and assess the overall results under realistic attack scenarios. The virtual environment is instantiated or destroyed on demand for each trainee, and the process can be repeated again and again. Nevertheless, the design and development of even a mainstream programme requires significant expertise, time, and effort by the trainer.

Thereafter, the trainee can follow the defined learning path to obtain knowledge and acquire new skills, complete a full programme, and earn a relevant certification [6]. However, the fact that someone fulfils the training and learning requirements does not mean that he/she will also adopt automatically his/her behavior in the digital world accordingly. On the contrary, several research activities have revealed that only a small percentage of the learnt concepts (around 10%-40%) is automatically embraced by individuals. This is an important problem for organizations, especially those ones that operate critical infrastructures, as non-compliance of their personnel to the defined security policies is deriving the deployed protection mechanisms inadequate and the underlying systems vulnerable to attacks. Thus, the real efficacy of training itself, even with advanced CRs, is still a perspective that needs to be significantly improved.

This paper presents the EU-funded CR, called THREAT-ARREST (www.threat-arrest.eu). The platform marshals modern training methods (i.e. emulation, simulation, serious gaming, and fabrication of realistic synthetic data) to enhance the learning experience for trainees. The overall process is fortified with pedagogical methodologies (i.e. Bloom's revisited taxonomy and Kolb's experience gaining life-cycle) to define the learning path and ensure the learning outcomes. Moreover, the educational scope can be designed in such a way that it will cover the requirements and demands for professional certification schemes from organizations like ISACA and ISC^2. This option will further increase the acceptability of a specific CR platform in the market.

The paper is structured as follows. Section II positions the THREAT-ARREST CR with respect to the related work. Section III presents the main CR capabilities and the tools implementing those capabilities, while Section IV draws conclusions and future work.

II. Related Works

A. Cyber Range Platforms

Overviews of cyber security training in critical infrastructures (e.g. nuclear energy, conventional energy, healthcare, transportation, and aviation sectors), are documented in [6]-[7]. Today, the demand for security experts is continuously increasing [7]. CRs constitute a promising solution of advanced training, which could fill the gap by enhancing educational material with hands-on experiences.

The majority of the CR platforms are developing automated mechanisms to ease the implementation of training scenarios, virtual labs, and the trainees' evaluation [6]-[9].

Online platforms, like, edX, Coursera, and Udacity, provide general-purpose training and offer main cyber security courses [6]. Specialized platforms, such as SANS [10], Cybrary [11], StationX [12], CyberInternAcademy [13], and AwareGO [14] focus on individual learners whose target is to sharpen existing or develop new skills. Nonetheless, such solutions fail when it comes to hands-on experiences on actual systems or CRs.

BeOne Development has developed its own platform for security awareness training [15]. This solution involves awareness videos, e-learning modules, and simulation modules. Thereupon, the BePhished simulator is used especially for training on phishing attacks. To ease the creation of training exercises, BeOne implements the Security Awareness Library that includes 28 learning contents. Cultural differences and multinational working environments are considered, as education is more effective if the learnt examples are correlated with the trainees' daily activities. This platform provides generic and pre-packaged programmes, organization-specific look and feel, or customized programmes which are designed in close collaboration with a client's experts. The BeOne solution offers generic teaching procedures for the core training and the advanced simulation-centric training focuses on phishing assaults.

ISACA implemented the CyberSecurity Nexus (CSX) platform [16]. It offers lectures and hands-on lab exercises on real systems. The learner gains experience by practicing main concepts and industry-leading methodologies. Capture-the-flag (CTF) exercises are also provided, improving the learners' technical capabilities. Trainees are evaluated and the target is to gain related professional certifications. Thereafter, the chief information security officer (CISO) for an organization can hire personnel with the required skills.

Kaspersky provides enhanced computer-based training programmes for all organizational layers [17]. Apart from online training, the tool offers benchmarking against industry/world averages, as well as realistic gamification and simulation. It implements an internal learning and educational schedule with constant reinforcement, provided automatically via a mixture of training formats, involving learning modules, tests, email reinforcement, and/or simulated phishing campaigns. The platform monitors the learners' progress through a user-friendly dashboard, providing also forecasts, trends, and live data tracking.

CyberBit's platform offers realistic simulation of cyber-attacks in a mirror system of a real network with a security operations center (SOC) [18]. This CR is composed of a virtual network (digital twin of a real setting), the traffic generator (benign data), the attack engine (malicious traffic), and the virtual SOC (learners' point of view). The target is to simulate hyper-realistic CRs. This solution offers various training scenarios, like penetration testing and incident response. The educators set up the training sessions that include session monitoring, trainee assessment, debriefing, and scenario administration. Scenario customizations are also supported through a graphical interface.

The THREAT-ARREST solution supports training on known as well as new advanced cyber attack scenarios, taking different type of actions, such as preparedness, detection and analysis, incident response, and post incident response. THREAT-ARREST offers monitoring, assessment, and security testing for various layers in the implementation stack, like:

- Network layer modules (such as honey pots/honeynet, firewalls, intrusion detection systems, etc.),
- Infrastructure layer (e.g. passive and active penetration testing, security monitors, etc.),
- Application layer (like code analysis, security monitors, and penetration testing).

The overall process starts by assessing the organization's security posture. The Assurance Tool estimates the current level of security and reports the most critical security issues, based on which the training process is designed. Thereafter, hybrid training programmes are developed, customized to the organization's demands and the underlying trainee groups. This involves the educational material along with serious games and the emulation/simulation of the CR system. THREAT-ARREST also supports continuous evaluation of: (a) the individual trainees' performance in specific courses; and (b) the efficacy of complete programmes across trainees' groups and the organization as a whole. Those assessments are utilized for the customization of programmes to the skills of individual trainees or adjustment at a more macroscopic perspective.

Table 1 documents a qualitative comparison for the above mentioned CR platforms. THREAT-ARREST incorporates all modern training features of serious gaming, simulation, and emulation in a unified manner, and provides continuous security assessment and training adaptation based on the trainee's capabilities.

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TABLE I. CYBER-SECURITY TRAINING PLATFORMS: A) THREAT-ARREST, B) BEONE, C) KASPERSKY, D) ISACA CSX, E) CYBERBIT, F) ONLINE TRAINING PLATFORMS. THE FOLLOWING NOTATIONS ARE UTILIZED FOR (Y)ES, (N)O, AND (P)ARIAL.

Feature	A	B	C	D	E	F
Automatic security vulnerability analysis of a pilot system	**Y**	N	N	N	N	N
Multi-layer modelling	**Y**	P	Y	Y	Y	P
Continuous security assurance	**Y**	N	N	Y	Y	N
Serious gaming	**Y**	N	Y	Y	N	P
Realistic simulation of cyber systems	**Y**	P	Y	Y	Y	N
Combination of emulated and real equipment	**Y**	N	P	Y	N	N
Programme runtime evaluation	**Y**	N	N	Y	Y	Y
Programme runtime adaptation	**Y**	N	Y	Y	N	P

B. *Adopting Training in the Workplace*

Even though there is an increasing need for modern security training and advance CR platforms (e.g. with serious games, simulation, emulation, etc.), the transfer of the learned capabilities from the trainees to their workplace and the adaptation of the organizational operations have been totally neglected in almost all cases (e.g. ([7], [8], [9]). Noncompliance of users with the security policies that the organization has defined is of main concern ([20], [8], [19]). If the personnel do not totally follow such policies, the effectiveness of the deployed defenses is lost. From the different compliance methods, effectual training is the most widely used one.

Nonetheless, only a few studies are assessing the effects of professional training to organizations and promote compliance policies in the workplace ([20], [8]). Also, only in rare cases theory is used to evaluate the aspects that affect trainees' compliance with security policies or even present empirical evidence from actual training. Ordinarily, it is believed that training programmes have to utilize procedures and material which can actively engage learners and motivate them to systematic cognitive processing of the underlying contents ([7], [6]). Apart from novel technical features (such as serious gaming and simulation), the continual communication between the instructor with the trainees is vital for the enhancement of the individuals security compliance ([7], [20], [6]).

Researchers usually integrate pedagogical principles as the main approach to advance learners' compliance ([8], [19], [6]). In 1998, Baldwin and Ford [21] defined the transfer of learning to the workplace as "the degree to which trainees effectively apply the knowledge, skills, and attitudes gained in the training context to the job".

However, it is recorded that approximately only 10%-40% of all training experiences would be transferred to the working environment ([22], [7], [8]). Furthermore, as time passes from the programme's completion, trainees tend to become less motivated in retaining the obtained operational behaviors (i.e. after twelve months). Therefore, for the currently supported technical solutions and methodologies, only a small percent of the learnt outcomes would be permanently transferred to the workplace. Thus, improving learning transfer constitutes the main concern of novel cyber security training platforms. This is also one of the main THREAT-ARREST goals including the developed continuous adaptation and assurance mechanisms, which are presented in the following section.

III. THE THREAT-ARREST PLATFORM

A high-level view of the THREAT-ARREST platform is depicted in Fig. 1. The main components are presented in the subsections below.

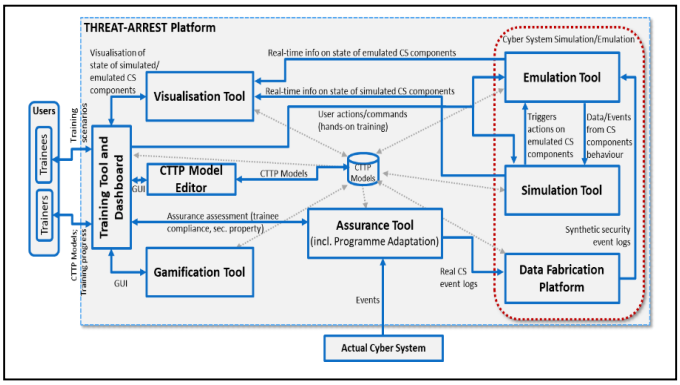

Fig. 1. The THREAT-ARREST platform

A. *The Assurance Tool*

The Assurance Tool provides continuous evaluation of the operational system's security posture via the integration of dynamic testing and runtime monitoring [4]. The tool also gathers system events at runtime and produces notifications which identifies the basis for designing realistic virtual labs (with emulated/simulated components and serious games).

The Assurance Tool performs a continuous runtime evaluation of system aspects that are significant for the definition of a Cyber Threat and Training Preparation (CTTP) programme. These features are determined in the CTTP model (security assurance sub-model). For example, the CTTP model determines the system components which should be monitored, the relevant events that are of importance (like user actions, external service calls, operating system calls, etc.), and the conditions which they have to satisfy. Moreover, it deploys dynamic system tests which are performed at runtime and are incorporated with monitoring to implement hybrid security evaluations [23], [24]. The gathered monitoring information and testing results are the operational system evidence. This data is parsed to simulation components and enables statistical profiling, as well as the production of realistic simulations.

B. *Hybrid Training*

The CTTP models can define virtual labs with hybrid training scenarios by combining emulated and simulated components. In this case, some of the system components are emulated (implementation of the full component functionality, i.e. a VM) while the rest ones are simulated (only deployment of the main part of the component's functionality/interactions, e.g. a simple programme that outputs a temperature value, representing a sensor of a smart home). Hybrid training becomes quite useful when the emulation of the entire system is not feasible or required, and obtaining hands-on experiences is requested for specific system components. With hybrid

scenarios, learners are expected to monitor, test, and act on emulated components, while observing the effects to the remaining cyber system and their propagation through simulation. In some occasions, simulation may be also preferred to retain the CR resources, as in practice it will be less demanding than emulation. The CR platform could also terminate specific emulated components at some time-point and continue with their simulated versions (e.g. in case that they would not be needed for a certain training phase), or decide to emulate components that were simulated in a previous training stage. Totally, the training scenarios that can be deployed by THREAT-ARREST vary based on:

- The *system coverage* level: With respect to this factor, scenarios can be distinguished into those engaging attacks that focus on: (i) single system components, (ii) clusters (e.g. subsets of interconnected) of system components, or (iii) all system components.
- The *attacks type*: With respect to this factor, scenarios are distinguished into those performing: (i) historic attacks, or (ii) live attacks that are executed as the simulated/emulated scenario is propagated by the CR platform.
- The required *response type*: With respect to this factor, scenarios are differentiated based on the required response to a security incident. Different responses are determined according to the different training stages. Such responses include [25]: (i) preparation/preventive actions, (ii) analysis and detection, (iii) containment, eradication, and recovery activities, and/or (iv) post-incident actions.
- The *trainee's profile*: With respect to this factor, scenarios are differentiated based on the cognitive trainee's profile, as disclosed by introductory security games and the trainee's performance on the training scenarios where he/she has been exposed so far.

The permitted variability forms based on the criteria above, are determined as part of scenarios constructing the CTTP programme. Via an Editor, the Training Tool supports the definition of CTTP models and programmes, the assignment of learning exercises/materials for CTTP programmes, allow trainees' responses to deployed threats, communication with the emulated/simulated components, assessment of the trainees' performance, as well as evaluation and adaptation of a CTTP programme as a whole.

Except from the CTTP models and programme definitions, the Training Tool supports a high interactivity level of the trainee with a training scenario, allowing him/her to respond and/or send appropriate commands to emulated/simulated components. Moreover, it continuously collects information concerning the emulation and simulation status, assesses in real time the scenario progress based on trainee's responses and their effects on components, and calculates the overall trainee's performance. The tool also validates the assumptions defined in the assurance model based on the trainee's responses to the instantiated scenario and produces notifications when such assumptions get violated. The Training Tool evaluates the trainee's performance and assesses and adapts the whole CTTP programmes. Finally, this tool interacts with the Visualization Tool for the effective training delivery.

C. Serious Games

Except from emulation, simulation, and hybrid-based training, a CTTP model can also configure serious games for different training modalities. Such training aims to advance skills to defend against attacks targeting users by exploiting human weaknesses (e.g. social engineering). By adjusting the games to the users' skills serious games can gradually advance the users' ability to defend against attacks. On the one hand this can be done by training the user to react in a certain way, i.e. following the assumptions from the assurance submodel as also specified within the security policies (PROTECT [26]). For example, if the targeted system applies a two-factor user authentication mechanism, requiring security tokens and passwords, it is considered that users would alter their passwords in a frequent basis and refrain from sharing the tokens. A relevant scenario in the serious game would cover this topic and aim to train the user to act according to the assumptions. For instance, trainees can be asked to share their security tokens to favor another person who gained their trust in the game (simulating a phishing attempt), but would be rewarded for the strategy of not sharing their token. On the other hand, users can learn about recent attacks in a quiz game which is provided with questions on recent social engineering attacks (CyberSecurity Awareness Quiz [27]), allowing the users to keep their knowledge about attacks up to date.

Games are also utilized for the initial profiling of trainees in order to disclose the trainee's cyber security skills and determine the appropriate form of training (and its difficulty) which could be sufficient for them. For example, an introductory game could be utilized for the evaluation of the trainee's familiarity with access controls, and based on it, drive any follow up training towards, for instance, emulation for a more hands-on exposure to access control aspects.

The Gamification Tool hosts various serious games (i.e. PROTECT [26] and the CyberSecurity Awareness Quiz [27]), scenarios, and training evaluation mechanisms, which allow a trainee to develop skills in preventing and being resilient to social engineering assaults (e.g. phishing campaigns, impersonation attempts). These games are driven by the assumptions and threats from the related security assurance CTTP models.

Finally, this tool can facilitate post training evaluations of trainees' awareness (in terms of knowledge and attitudes) for the trained attack types.

D. Emulation

Based on the CTTP model, the Emulation Tool can emulate software and hardware components, defined as Software Architecture Layer (SAL) and Physical Architecture Layer (PAL) elements [5]. The tool creates live instances of SAL and PAL components like VMs, performing the available operations/services for them, and enabling data and stimuli flows utilizing the deployment and network links connecting them in the SAL, PAL, and deployment sub-models. Emulation is utilized when the behavior of specific SAL/PAL components cannot be sufficiently described in detail to permit the

simulation of its behavior, or when trainee's hands-on experience in controlling and observing these components is necessary.

With emulations, there are also emulated clients of the cyber system requesting services from it, and trainees have to interact with the emulated components (e.g. login a VM) and execute specified actions to defend the related components, and via them, wider parts of or even the entire emulated setting. For instance, after accessing a VM, trainees can make use of monitoring and testing tools to identify attacks, examine them, and respond to them in real time (e.g. strengthening access restrictions, deactivating some functionality, etc.). Learners can also be assigned to groups with accountability of defending certain system components or even act as attackers to insight on how an attack can be performed.

E. Simulation

The CTTP model can deploy the simulation of attacks on some system components or the propagation of the side-effects on other parts of this system [5]. For example, the provided CTTP model information can drive the simulation of distributed denial of service (DDoS) attack propagation, targeting a smart home gateway, as well as the effects on the simulated SAL and PAL components. The propagation of those side-effects is controlled by simulating the response operations determined for SAL and PAL elements and enabling data and other stimuli (e.g. calls) flow across components via the links of the SAL and PAL sub-models. The attacks' side-effects might be also propagated from the PAL to the SAL level (and vice versa) based on component links determined in the deployment model of the CTTP model. Simulations can vary based on the difficulty level which they present to the trainee. This level is controlled by limiting the degree of information which is available for an attack, the time when such information becomes available following the attack, and the consistency of data generated by the different security mechanisms of the system and the external utilized assessment tools.

To enable realistic simulations, the THREAT-ARREST framework is continuously monitoring the real operational system and logs any significant events related to it. The events to audit and their analysis type is determined by the assessment measures of the assurance submodel. Then, the captured assurance relevant events are statistically profiled. Statistical profiling covers event metadata (such as the timing of their happening or other features like their sender and receiver) and – where allowable by the applicable security policies – the actual event payload (like data passed among the components, parameter values for component operation calls, size of files written or read, etc.).

F. Visualization

The Visualization Tool enables the graphical representation of emulations and simulations, the effect of training actions on emulated/simulated components, and the state of the relevant components.

Utilizing the visualization framework, the THREAT-ARREST platform's operator can choose the desired training scenarios and configure their parameters. Furthermore, the platform can parse and visualize the CTTP model and the submodels described in the sections above, and present the relevant graphs to the users. The operator can use those graphs to pick the system parts that will be emulated or simulated. The Visualization Tool is also responsible for the representation of the status of the emulated/simulated components and the effects of the training actions.

G. Data Fabrication

The Data Fabrication Platform (DFP) [28] is a web-based platform for generating high-quality structured data for testing, development, and training. The methodology used is termed "model-based rule-guided fabrication". DFP consumes data declaration directives (data model or metadata) along with user-defined rules as input, creates a Constraint Satisfaction Problem (CSP), and solves the problem using a proprietary CSP Solver, which has been used for verifying IBM hardware systems for over a decade.

Two types of synthetic data have been used for the THREAT-ARREST objectives:

(i) Static general-purpose synthetic data, such as health records, for the needs of setting/performing a given training scenario;

(ii) Static or dynamic (interactive) security (event) logs for cybersecurity training in the context of a training scenario, such as security logs regarding malicious (anomalous) accesses to a server hosting a database of health records.

In the first case (i), data is modelled in advance via the DFP web-based user interface and fabricated off-line, before a training session starts. Fabricated data is populated in predefined databases and/or predefined file locations to be deployed and consumed in a virtual lab environment.

In the second case (ii), a dedicated data fabrication functionality has been exposed through REST API so that other platform components can dynamically request data fabrication. For instance, during scenario initialisation the Training Tool initialises a data fabrication process while upon successful confirmation of log fabrication finalisation, the Emulation Tool fetches the fabricated logs and deploys those in the corresponding VMs of the Virtual Lab environment.

IV. CONCLUSIONS

This paper described the THREAT-ARREST approach – a cyber ranges platform for advanced cyber security training for medium to large organizations. Initially, the organization's real system is analyzed, disclosing the most severe vulnerabilities and threats. Thereupon, a training programme is developed which adheres to the organization's specific requirements. The various elements are defined as CTTP models and the overall learning processes are assessed and adapted at runtime. Apart from the typical on-line educational content (e.g. lectures, videos, tutorials, etc.), the advanced hybrid training incorporates serious games and emulated/simulated virtual labs. The overall solution can cover the training against known and new attacks, and prepares trainees to detect, respond, and mitigate them under realistic conditions.

Future work includes extending end user validation of platform capabilities with organizations of different domains (energy, healthcare, smart shipping), extending platform integration and federation with other Cyber Ranges both on a technical level scenario interoperation and on a conceptual (capability, taxonomy) level to further expand and align with end user needs of training.

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