SIS-ASTROS: An Integrated Simulation System for the Artillery Saturation Rocket System (ASTROS)

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Abstract: Simulation is a valuable technique used by the military to support personnel training. A trend in current military training is the combination of different types of simulation in an integrated setup. Observing this trend, the Brazilian Army is making efforts to develop integrated simulation solutions. This paper presents the conception of an integrated simulation system of the Brazilian Army Artillery called SIS-ASTROS. Besides the integrated setup connecting different types of simulators, a major contribution in the scope of the SIS-ASTROS is the presentation of the virtual tactical simulator to train mid-rank officers in activities regarding the coordinated deployment of ASTROS artillery batteries on the battlefield. This simulator not only addresses constructive simulation aspects but also virtual ones. Due to its design, the conception of this simulator on its own is already an important innovation. This paper presents the key components of the integrated simulation system, highlighting the main contributions in the research and development of the virtual tactical simulator.

1 INTRODUCTION

Simulation techniques have a paramount role for demonstration, training, and analytical tasks in the military domain (Hill and Miller, 2017) (Smith, 2010). Computer-based simulation for military training is a key asset for users not only to enhance their technical skills but also to collect and refine military tactical and strategic doctrine knowledge before real-world activities. Moreover, the use of simulation-based training can diminish the costs and risks associated with the use of real-world equipment or mobilization of a large contingent of resources and people. In particular to the tactical training of military doctrine, it is important to highlight the simulation system functionalities that provide an intermediary level between a virtual technical simulator and a constructive one (Department of Defense - DoD, 2013). Thus, a blended simulation can be explored to train tactical skills of mid- or low- ranked military officers.

To the improvement of state-of-art simulation-based military training, a collaboration between the Brazilian Army and the Federal University of Santa Maria - UFSM approached the research and development of high-fidelity simulation systems to provide a qualified training experience to military personnel. A relevant part of this effort is directed to the research and development of the SIS-ASTROS project, which involves an integrated simulation system architecture for the tactical employment of batteries of the Artillery Saturation Rocket System for Area Saturation (ASTROS) system (AVIBRAS, 2019). This simulation system architecture is composed of a set of standalone simulators particularly adjusted to the training of the military personnel in the coordinate handling of the different military vehicles that make part of an ASTROS Battery. In this project, alternative simulation problems are approached through computer-based training and virtual technical simulators, along with the capacity to train higher-level tactical skills of the battery commander in the recognition and deployment of such battery units in different tactical positions in a virtual battlefield terrain scenario. With a virtual tactical simulator - the SIS-ASTROS Sim-

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ulation System, training users can interoperate with other kinds of simulation systems, such as constructive ones, allowing the development of fully integrated and enhanced simulation exercises. The major innovation in this system is the proposal of the virtual tactical simulator for training the military aspects related to what is called Position Recognition and Occupation (PRO) activities of ASTROS Batteries, which relates to training the skills of battery commanders in performing tactical deployment activities.

This paper presents the SIS-ASTROS integrated simulation system, focusing on the most important scientific and technological contributions, mainly concerning the conception and development of the virtual tactical simulator.

2 BACKGROUND

2.1 Life, Virtual and Constructive Simulations

There is a discussion among simulation users about the ways of employing different types of military simulation systems. However, a consensus among the practitioners in this area is that there is a clear benefit of using live, virtual, and constructive simulations for military training (Department of Defense - DoD, 2013), a benefit that is even augmented when these three types are combined in joint LVC simulations (Hodson and Hill, 2014) as investigated in this work.

Once constructive simulation handles higher levels of abstraction, concerning strategic decision-making aspects, virtual simulation is concerned about training specific operational and tactical skills, while live simulation comes closer the reality, training operational and "hands-on" skills (Hodson and Baldwin, 2009). Despite this LVC classification, there are intermediary zones between virtual and constructive, and between virtual and live simulations (Meyer et al., 2014). These intermediary zones can be explained by the flexibility of the virtual simulations, which can present aspects closer to live simulations from one side, or closer to constructive simulations on the other side. Considering the first, the use of virtual simulations targets training technical or operational skills regarding given equipment. Thus, it is possible to call this specific application of virtual simulation as technical-virtual simulation. The second application of virtual simulations, closer to constructive ones, targets training not the handling of particular equipment, but its employment concerning tactical aspects, such as how to tactically select the best path for a vehicle (or a convoy) to move over a given terrain. This usage contrasts with the constructive simulation, which is concerned with higher-level (strategic) aspects, which completely abstracts finer grain details of the specific terrain, for instance. Thus, it is possible to name this second flavour as virtual-tactical simulation.

The virtual-tactical simulation provides a computer-based virtual environment in which low- or mid-level decision-makers, such as the commanders of smaller fractions of troops such as a cavalry platoon or an artillery battery, can train their skills in how to move and employ their units in a given terrain to accomplish their missions. To accomplish this goal, this type of virtual simulation must present a realistic scenario that presents and integrates all the necessary elements to exercise the skills of these low- or mid-level commanders.

2.2 Related Works

In (Balint et al., 2015), the authors propose the automated creation of simulation setups from documents describing military operations. These documents present several details about the terrain, the considered enemy, and the procedures that the military personnel has to execute to achieve a military goal, i.e. the doctrine. They propose a framework, called VerbsEye, which is a text-to-scene system that relies on descriptive texts to generate scene scripts and agents' behavior scripts for virtual environments. In the SIS-ASTROS project, the representation fidelity to the military doctrine of the Brazilian Army is also a relevant aspect. In (Mamdouh et al., 2012), the authors present a realistic behavioral model for hierarchical coordinated movement and formation for real-time strategy and war. It is capable of propagating orders through a long chain of command, starting at a brigade level, down through intermediary levels to individual units deployed on the field. However, differently from SIS-ASTROS, their work does not provide the integration of different simulators.

The work developed in the SIS-ASTROS project can also be understood as a serious game. Among other reasons, it uses several aspects of digital games to teach and train skills (Susi et al., 2018) related to the command and operation of the ASTROS system. The usage of serious games in military training has a long history and many works about this usage can be found in the literature (Smith, 2010) (Pallavicini et al., 2015). The French military developed a serious game for massive training and assessment of soldiers that are involved in forwarding combat casualty care (3D-SC1) (Pasquier et al., 2016). Despite the usage of 3D techniques similar to those used in the SIS-ASTROS project, the goal of the 3D-SC1 is more focused on training the users in technical-operational procedures, while particularly the virtual-tactical Simulator in the SIS-ASTROS project focuses on training tactical skills.

In summary, the literature on military simulation systems indicated that the SIS-ASTROS project is a pioneer in integrating different types of simulations in the same setup. It is possible to find related works that "scratch the surface" of this problem, providing certain levels of integration. However, the SIS-ASTROS project approaches the integration of different types of simulation, providing specific contributions in each of the different simulation areas, as well as the proposal of the virtual-tactical blended approach.

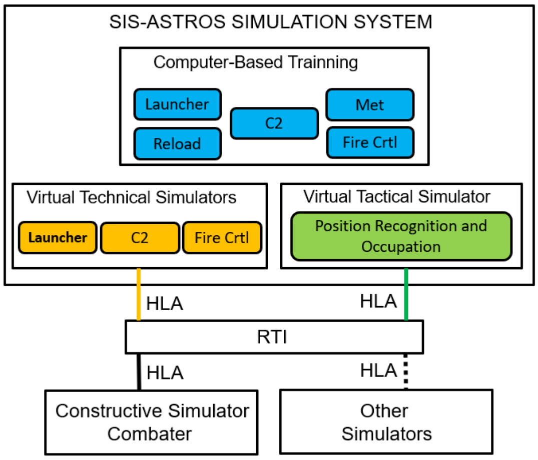

Figure 1: Overall schematic representation of the SIS-ASTROS elements and its interface with external simulators.

3 SIS-ASTROS OVERVIEW

Figure 1 presents an overview of the SIS-ASTROS architecture, with its internal components and external interfaces. The boxes inside the "Computer-Based Training" represent the educational software for each vehicle member of an ASTROS Battery. The goal of this software is to provide the first contact of each battery vehicle to their future users. For some of these vehicles, there also is a corresponding Virtual Technical Simulator (SVTec). They are physical cabins mimicking the exact aspects of the corresponding vehicles. Besides being used for basic operational training purposes, these Virtual Technical Simulators can also be used in an integrated manner, among themselves, or between them and the Virtual Tactical Simulator (SVTact). Used to train the tactical skills of a Battery commander, this Virtual Tactical Simulator can operate stand-alone, integrated with the Virtual Technical Simulators, or integrated with other simulators outside the SIS-ASTROS architecture. For instance, the Virtual Tactical Simulator can be integrated with the Constructive Simulator used by the Brazilian Army (called Combater™), which is responsible for the development of strategic level simulations for higher-rank commanders. The integration between the simulators is performed following the IEEE High-Level Architecture (HLA) standard (IEEE Std 1516-2010, 2010).

The integrated usage of different simulators is one of the major requirements posed by the Brazilian Army in the development of the SIS-ASTROS project. Hence, it is possible to perform simulations integrating the Virtual Technical Simulators only, or them with the Virtual Tactical one, or this last one with a Constructive Simulator outside the SIS-ASTROS architecture. In practice, it is also possible to integrate all these three types of simulators in a single simulation exercise from a self-developed multiresolution solution (Paul et al., 2017). These possibilities for different integration setups provide means to explore the simulators in multiple ways depending on the goal of a given simulation exercise. The data provided by a higher-level simulator can also be used to trigger situations in the lower-level ones. For instance, data about the employment of forces decided in the higher-level Constructive Simulator can be used to trigger the displacement of an ASTROS battery. Such displacement means the need of executing Position Recognition and Occupation (PRO) actions developed in the Virtual Tactical Simulator. Once the PRO decisions are taken, details about the enemy targets can be passed by the Virtual Tactical Simulator to the Virtual Technical ones to perform a simulated rocket launch.

4 THE VIRTUAL TACTICAL PRO SIMULATOR

The Virtual Tactical Simulator is a key element in the SIS-ASTROS simulation system. It links the high-level constructive and low-level technical perspectives, providing means to train tactical skills of mid-rank military officers. This section presents details about its design, implementation, and operation.

4.1 Architectural Design of the Virtual Tactical PRO Simulator

The goal of the Virtual Tactical Simulator is to provide simulation-based means to exercise higher-level PRO activities executed by ASTROS Batteries commanders and their direct auxiliary staff. These users are responsible for tactical decisions related to the deployment of an ASTROS Battery. Among others, they need to choose appropriate tactical locations to be used and the route to move from one position to another. To successfully perform such activities, it is necessary to observe many general rules regarding the correct usage of the resources and constraints of given equipment, as well as the environmental and battlefield conditions, such as weather, time of the day, and enemies and allies' troop locations.

Training tactical aspects regarding the employment of ASTROS batteries require the usage of maps of the terrain area where the PRO activities have to be executed. In practice, battery commanders need to analyze the terrain locations that could be used, for instance. Besides that, once a given location is selected on the map representation of the terrain, it is important to get information about how the terrain looks like in the reality, how dense the vegetation is there or if terrain locations in consideration are floodable or not, or to analyze if a bridge in a given movement route can support the weight of the vehicles that compose the battery convoy. To exercise such aspects, the Virtual Tactical Simulator was designed to present two user-interface perspectives, one is two-dimensional (2D) and another three-dimensional (3D).

In the 2D perspective, the users interact with a map via a very large digital table. This touch-screen simulation table allows the users to select positions and routes in the simulated map, besides performing all the simulation activities of a PRO execution, such as parking the vehicles in a given location, disembarking/boarding staff out/in the vehicles, selecting the vehicles that will perform a given action, firing and reloading the launchers, among others. In technological terms, the digital table is a capacitive touch-screen interface with 80" full-HD resolution, which allows multiple touches, allowing the interaction of more than one user at the same time.

In the 3D perspective, the users visualize the details of the simulated terrain, such as the conditions of a bridge or the vegetation density. In effect, the simulator was designed so that the 2D perspective is presented on a digital touch table, while the 3D perspective is presented on a Wall-TV panel. This Wall-TV is a LED-Wall with 146" full-HD resolution, providing higher resolution compared to other alternatives to implement such a wall. These elements can be seen in the representation of the simulator depicted in Figure 2. This figure also shows a third element, which is the instructor terminal. That is the place where the instructor sets up the simulation exercises through a 2D visualization interface, creating an entire operational situation that has to be examined by the trainees. All these three elements are interconnected and synchronized in such a way that the instructor may interfere in the running simulations to include training challenges, change simulation parameters, and examine all the simulation commands performed by the trainees.

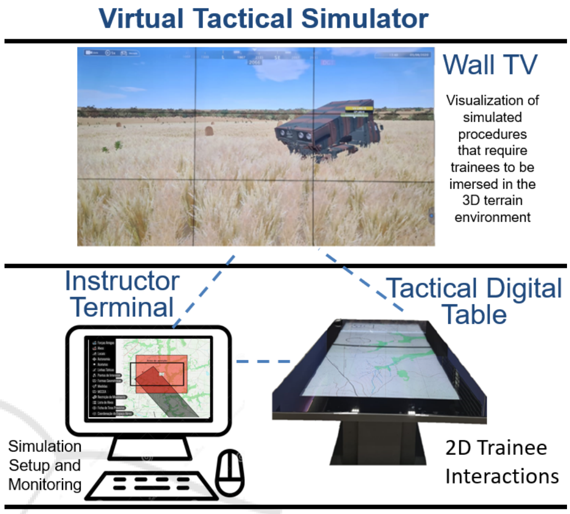

Figure 2: SIS-ASTROS Virtual Tactical Simulator Setup.

Understanding the peculiarities of a project involving the Federal University of Santa Maria - UFSM and the Brazilian Army (i.e. two different federal government entities) was crucial to the choice of an adequate software process model to satisfy the needs of the involved parties. Due to the existence of contractual agreements requiring the delivery of project artifacts at fixed intervals of time (e.g. the specifications of requirements for each project goal, the hardware and software technical specifications, the incremental versions of the simulator, etc), the plan-oriented approach for software development served as the basis for the definition of such a software process used in the SIS-ASTROS project. Agile methods were also used in activities of software implementation and testing, and team management, emphasizing the principles of collaboration and communication, in addition to allowing the answering of requests for software change. The key issues encountered during the project development along with the adopted software engineering solutions were documented. Thereafter, these pieces of project development experiences were described as a set of lessons learned (Brondani et al., 2019a). They can be reused in the development of similar projects.

Constructed as different layers that expand the computing resources of the Unity 3D engine (Unity-Technologies, 2022), the software implementation of this Virtual Tactical Simulator was designed to be modular. The software packets composing the architectural design are organized as follows: **AI, Behavior, Cameras, Core, Events, Networking, Tasks, Terrain Engine** and **UI**.

The **AI** packet hosts the classes responsible for creating a hierarchical data structure that is used to construct the terrain navigation graph (Brondani et al., 2019b). This graph maintains the terrain information that is used in the computation of various kinds of simulated agent behaviours. Storing all the data related to the roads of the virtual terrain, it is used to support the autonomous displacement of vehicles along the roads during the execution of the simulations (Brondani et al., 2017) (Brondani. et al., 2018).

The **Behaviour** packet contains a set of classes implementing the physical behavior of the entities representing the military personnel, vehicle, and rockets (Menezes and Pozzer, 2018). The **Soldiers** packet is responsible for all functionalities and behaviors of the entities representing the military personnel in the simulations. It has also a structure that enumerates the simulation state of these entities.

The **Vehicles** packet contains classes implementing the behavior of each battery vehicle, i.e. **VehicleTypeControler**. These classes inherit attributes and methods representing the common behavior of all the vehicles in the simulator. The **Rocket** class implements methods that control the launching, the noise direction, the explosion once the rockets hit the target, among other particular aspects related to the rocket launching.

The **Cameras** packet organizes the classes responsible for controlling the cameras used in the 3D simulation projection presented in the Wall-TV. It also controls the cameras used as viewpoints helpers, used to zoom a given part of the simulation. There are three control modes for the cameras, which can be controlled via joystick or mouse: *follow, orbit* and *fly*.

The **Core** packet contains the **Projection** class, which is responsible for the conversion of coordinates from **UTM** to geographic latitude and longitude representations. The **Events** packet contains the classes responsible for handling the different events triggered during a simulation, such as the beginning of a simulation, the changes in the focus of the cameras, the loading of vehicles, among others.

The **Networking** packet is responsible for handling the objects that are used in different computer stations that compose the simulation system, i.e. the instructor terminal, the tactical digital table, and the Wall-TV. These elements are connected to a network in which they need to be synchronized. This synchronization is related to the semantic elements of the simulation, for instance synchronizing the effects of a certain simulation condition both in the Wall-TV and the digital table.

The **Tasks** packet contains the classes responsible for handling all movements performed by the battery. Moreover, it contains another packet, called **Battery**, representing the classes responsible for the activities related to the PRO implemented in the simulator. Examples of such activities are the waiting position and fire position recognition and occupation, etc.

The **TerrainEngine** packet contains the classes that handle the 3D visualization in the Wall-TV. They implement methods to load data about the terrain features, such as roads (Torres et al., 2019), rivers (Menegais et al., 2021), vegetation (Franzin et al., 2019), elevations, physics (Kaufmann et al., 2021), etc. Finally, the **UI** packet contains the classes that handle all user interface features, both of the instructor terminal and the digital table.

4.2 Operation Possibilities

Following the military doctrine related to human resources training, the Virtual Tactical Simulator can be used in the instruction and exercise modes, which are detailed in the following.

The instruction simulation mode is dedicated to teaching-learning activities that aim to train military commanders in how to fully employ an ASTROS Battery. In this mode, the instructor creates the entire simulated military operation along with specific teaching goals, so that the trainees learn certain skills. It is possible to create a simulation to present a certain problem-solving situation and the course of actions to solve it so that the trainees learn and build up their knowledge concerning that pedagogical goal. It is also possible to reproduce certain aspects of the doctrine in the simulations or to create different types of simulation setups focusing on the learning of a given doctrine procedure. The instructor can interfere at any time in such simulations. For example, the instructor may change the difficulty level of a given setup by inserting particular simulated military problems (SMP), which have to be solved by the trainees. The usage of SMP represents an important tool to realistically represent situations that have to be handled by the users of the ASTROS Batteries in a real-world situation.

The exercise simulation mode is used to train the abilities of more experienced military staff who has already the basic formation in how to employ an ASTROS Battery. This mode can be specifically used to train the commanders of ASTROS Batteries in isolated battery operations or the context of a larger military maneuver. In the first case, an instructor can create the whole simulated situation, and interfere in it by including SMPs at any time. Notice, however, the goal here is not to teach skills as in the instruction simulation mode, but it is to train the effective application of such skills. The goal is to provide a simulated environment in which military staff members can exercise their knowledge, enhancing their skills in the employment of the ASTROS Batteries.

In these simulation modes, instruction and exercise, the Virtual Tactical Simulator can be used as a stand-alone simulator, or integrated with other simulators. In the stand-alone option, the Virtual Tactical Simulator is executed without communication with any other simulator. In the integrated option may execute in different setups, considering the integration only with a Constructive simulator, or only with Virtual Technical Simulators, or with both of them, depending on the simulation purposes under concern.

In all forms of operation, it is possible to record the details of the simulated setup and the actions performed by the users so that after-action review (AAR) tasks can be performed. AAR represents a valuable way of developing a structured review or debriefing over the simulation exercises.

5 GRAPHICAL USER INTERFACE

The virtual tactical simulator offers two distinct visualization perspectives: one in 2D and another in 3D. These interfaces, as well as the integration between them, are presented in detail in the following.

5.1 The 2D Interface: Digital Table

The main interface provided by the virtual tactical simulator is the interactive digital table, which presents the simulated scenario in two dimensions. This interface allows the user to interact with the system by executing a number of actions, such as selecting routes, determining areas of interests, e.g. tactical positions, among many others. The digital table allows the visualization of two different types of images, which are the topological maps and the satellite images. The topographical maps are constructed from vector files (scale 1:50.000) which describe regions, names of locations, roads, rivers, among other features of the terrain. The satellite images present the real-world environment, allowing the observation of details related to the type of vegetation, rivers, lakes, type of the terrain, among other details. While the topographical maps are stored in relatively small-sized files, the satellite images may require the use of large data volumes. For the developed scenarios in the current version of the simulator, the satellite images are composed of files with 8 GigaPixel (GPixel), representing approximately one pixel every half squared meter of the represented terrain. To manage such a huge file, a multi-resolution approach was adopted (Backes et al., 2017).

The construction of the 8 GPixel image required a large development effort once it is the combination of a large number of smaller satellite images individually collected. Besides differences related to the color distribution, they covered several overlapping regions. To address this problem, a technique was developed to merge these images, handling the overlapping regions, and adjusting the histograms. At the end of this merging process, the resulting image was submitted to a multi-resolution and compression process, allowing the usage of a smaller space for its storage. Figure 3 presents an example of an 8 GPixel satellite image used in the simulator.

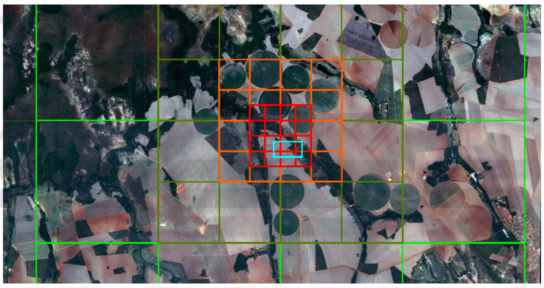

Figure 3: Example of an 8 GigaPixel satellite imagery (Backes et al., 2017).

The interface provided by the interactive digital table allows the user to execute many commands over the displayed map. The user can insert areas of interest, such as tactical positions, as well as to send orders to the simulated battery, such as select individual units to move to a given location, load the launchers, and many other commands. To avoid overcrowding the interface with buttons, a context-sensitive interface approach was adopted. Depending on the area in which the user clicks, i.e. in the type of the tactical area, a specific menu is exhibited with the specific commands that can be executed in that area in that given moment. Figure 4 presents the process of selecting and drawing tactical positions on the map, within a given area. The gray pop-up menu located almost in the middle of the map allows the user to draw other tactical positions inside that area. In Figure 5, the menu for the possible battery actions in the context of a given tactical position is presented.

Figure 4: The usage of the context sensitive menu in the process of planning the tactical positions of the battery: Pop-up menu active to select the positions.

Figure 5: The context sensitive menu for a given tactical position displaying four icons for the following actions: occupy area, identify area, delete area, and reload launchers.

5.2 The 3D Interface: Wall-TV

For the 3D interface, the goal is to provide the maximum virtual realism possible. To imitate the real-world scenario as realistically as possible but keeping the system responsiveness, concerns related to the memory and processor usage are taken into account in the simulator. The mesh of the terrain is rendered using up-to-date shader techniques. Vegetation is rendered using billboards and 3D models, along with optimized data structures on GPU (Franzin et al., 2019). Billboards are used to represent grass and distant trees. For those trees that are close to a camera, 3D multi-resolution models are used. Figure 6 presents examples of the graphical elements that are part of the virtual scenario.

5.3 2D-3D Interfaces Integration

The simulator is divided into three instances, each one running in one of the nodes that compose the Virtual Tactical Simulator, i.e. one running in the Instructor Terminal, a second running in the Tactical Digital Table, and a third running in the Wall TV. This last instance is the one that controls the entire simulation, i.e. it is a simulation server. The simulated agents' actions of movement are performed in this instance due to the large amount of represented terrain details, along with the behavior of the agents governed by the AI algorithms. Moreover, the instance running in the Wall TV also stores the information for the execution of the After Action Review (AAR) tasks. The other two components of the simulator are synchronized with the Wall TV through a synchronization network available in the Unity engine, which allows the synchronization of variables called syncvar. Once a syncvar variable is updated in the Wall TV, this update is propagated to the other two instances running in the other simulator nodes.

6 CONCLUSION

Computer-based simulation represents an important asset to train military forces. Despite the evolution of the different tools used in the scenario of military simulation, there is a lack of solutions that integrate the different levels of simulations, i.e. Live, Virtual, and Constructive. To address this issue SIS-ASTROS integrates constructive and virtual simulation. In essence, this paper approaches the SIS-ASTROS advances concerning this integration and the design of the virtual tactical simulator.

As future work it can be cited the integration with Live simulation in the SIS-ASTROS setup, and the consistency and robustness of the entire system under intermittent and faulty connections situations.

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Figure 6: Examples of the different kinds of vegetation, rivers and roads in the 3D Interface.

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