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Can current synthetic environment technologies solve all correlation issues?

CUSTOMER: Ministry of Defence

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EXECUTIVE SUMMARY

UNCLASSIFIED

Can current synthetic environment technologies solve all correlation issues?

Problem area

In a distributed simulation environment it is important that all participating simulation systems have a similar representation of the environment in which the mission is performed. However in the current paradigm used each simulation system is responsible for its own synthetic environment. This means that ensuring correlation between the different representations of the synthetic environment is one of the challenges when setting up a distributed simulation exercise.

Technological advances, like the introduction of real-time synthetic environment generation and the introduction of dynamic changes in the synthetic environment, make the challenge to ensure sufficient correlation even more challenging in the future.

Description of work

This paper is based on research done in the Mission Training through Distributed Simulation (MTDS) research program that NLR is performing. It gives an overview of what correlation of a synthetic environment means and what the typical sources of correlation issues are. Next a process is proposed to better manage correlation of the synthetic environment while setting up a distributed simulation exercise. The impact of recent technological developments on the quest of achieving correlation is also assessed. Based on all these elements it is finally discussed if the current technology available is sufficient to solve correlation issues in the synthetic environment.

Results and conclusions

By using Modelling & Simulation as a Service (MSaaS) technology a central representation of the environment can be created, which makes it easier to ensure correlation between participants in a distributed simulation exercise, since data

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processing and modifications can be made in one central place. This also allows dynamic changes to the environment to be introduced, without making the challenges of achieving correlation even harder. This is a paradigm change, as current simulation systems are responsible for their own synthetic environment.

Distributed simulation exercises will always be a mix of state-of-the-art and legacy simulation systems. And there will always be systems participating with different technical capabilities. This means that MSaaS based synthetic environment services alone are not the only solution. Therefore it is also important that the required amount of synthetic environment correlation is managed during the process of developing the distributed simulation exercise. A method and activities to be performed for this are proposed.

Applicability

The results of this work are primarily applicable to the development of distributed simulation exercises. The results will be included in the MTDS Reference Architecture that is being created in the MTDS program.

But the conclusions on how to minimize correlation issues in the future can also be used when specifying the requirements for new simulation systems. If these include support for common synthetic environment services correlation issues can be reduced in the future.

GENERAL NOTE
This report is based on a presentation held at the Simulation Innovation Workshop (SIW) 2020, Orlando (USA), 10 – 13 February 2020.

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Contents

Abbreviations

ACRONYM	DESCRIPTION
CAS	Close Air Support
CGF	Computer Generated Forces
DSEEP	Distributed Simulation Engineering and Execution Process
JTAC	Joint Terminal Attack Controller
LOS	Line of sight
MSaaS	Modelling & Simulation as a Service
NLR	Royal Netherlands Aerospace Centre
RADM	RIEDP Abstract Data Model
RIEDP	Reuse and Interoperation of Environmental Data and Processes
SE	Synthetic Environment
SISO	Simulation Interoperability Standards Organisation
SME	Subject Matter Expert

Abstract

Ever since the first distributed simulation exercises were set up in the 1990's, it has been a challenge to achieve a correlated synthetic environment between all the participants. Over the years many efforts have been done to identify and solve such correlation issues, which include tools to compare different representations of the same environment or standards to ease sharing synthetic environments between different participants. But, given the unique requirements and technological capabilities of different simulation systems, correlation issues remain a challenge when setting up a distributed simulation.

Recent years have seen many new technologies for the representation of the synthetic environment in simulation systems. For example, increased amounts of detail in the environments, trends to reduce the manual effort in the synthetic environment preparation, and generation of synthetic environment during runtime in the simulation system. Do these technological advances help us to solve the correlation issues or do they introduce even more challenges?

This paper presents research on the topic of correlation that has been performed recently. It discusses a proposed way to manage correlation within a distributed simulation exercise, where the aim - make all synthetic environments identical - is dropped. Instead the synthetic environments should be sufficiently correlated to have the same perception of the environment and thereby the same execution of a mission. This paper also looks at the impact of new technologies on correlation, how to make optimal usage of these technologies, and achieve sufficient correlation with these technologies.

1 Introduction

When setting up a distributed simulation exercise involving different simulation systems, one of the challenges is to provide the operators in each of these systems with a common representation of the synthetic environment (SE), e.g. they should see the same terrain, infrastructure, buildings or weather. In real-world operations everybody is obviously operating in the same environment, but in simulation systems this is not so obvious. To reduce the dependency between systems and to reduce bandwidth requirements the common paradigm in the simulation community is that each system is responsible for its own representation of the synthetic environment. When combining different systems in a distributed simulation exercise, this can lead to a different representation of the environment across the operators.

This was already recognized by Schiavone [1] in 1997 when he wrote that we need to “insure a sufficient degree of homogeneity between the essential elements” and that “the absence of ... unfair advantages is a necessary condition for the existence of ... fair play”. More than 20 years later these two statements are still valid.

Over the years many approaches have been tried to reduce synthetic environment correlation issues among distributed exercise participants. These include sharing the runtime databases used by the simulation system, using a common source dataset to construct the synthetic environment databases from and various initiatives to streamline the synthetic environment database production process and be able to generate correlated output for various systems from one process. Tools have also been developed to compare and test different synthetic environment representations and determine their correlation. For example by providing side-by-side views of a location in two databases or by testing elevation and line of sight between different environment representations.

However, even with all those best practices and solutions in place, assuring that the synthetic environment is correlated in a distributed simulation exercise is still a challenging and time-consuming activity. New technological developments, like dynamic synthetic environments or real-time terrain generation, have an impact on correlation as well. This leads to the question if we can handle correlation efficiently in future distributed simulation exercises with the current approaches and technologies.

In this paper we will try to answer the question how to handle synthetic environment correlation in future distributed simulation exercises. To be able to do so, we will first discuss what correlation is. Next, it will be discussed which sources of correlation issues are typically encountered in a distributed simulation exercise. Afterwards a process to manage the required correlation is proposed, followed by a discussion on how new technologies affect correlation. Finally conclusions are drawn and a way forward is proposed to handle correlation in a distributed simulation exercise.

2 What is correlation?

Before discussing ways to handle correlation and how new technologies affect correlation, it is important to have a good understanding of what is meant with correlation of the synthetic environment in a distributed simulation exercise. A common misunderstanding is that correlation means that the representation of the synthetic environment should be exactly the same in all participating simulation systems. This is practically impossible and striving for exact similarity is costly and time consuming. Different simulation systems have been designed with different requirements and have different technical capabilities. For example, an infantry simulator has been designed to show a detailed representation of a small area, possibility including an indoor representation of buildings. A flight simulator on the other hand has been designed to be able to show a much larger area and has been designed in such a way that flying through the synthetic environment at high speed is possible. When these two systems are used together in a distributed simulation exercise it is very hard to ensure they represent exactly the same synthetic environment.

But representing exactly the same synthetic environment is not required either. To be able to use the distributed simulation exercise effectively for its aim, all the participants should make the right decisions in the mission. This means that the synthetic environments should be correlated enough for the operators to make the correct decisions. But, taking the infantry and flight simulator as example again, a more detailed representation of a building in the infantry simulator is not a problem as long as it does not influence the total flow of the mission.

So what are the characteristics of correlation? What ensures that an operator makes the right decisions in his mission while observing the synthetic environment? The following three aspects of the synthetic environment representation are most crucial:

1. The **presence** of synthetic environment elements. Are relevant elements present in all representations of the synthetic environment and, when they are present, can they be seen from the same position? This aspect includes the line of sight (LOS) checks that are commonly performed to assess the correlation of synthetic environments.

2. The **appearance** of the synthetic environment elements should be similar enough for the operator to interpret the environment in the same way. When the environment is shown visually, this means that for example a building should be represented in such a way that each operator can recognize it as that specific building, even though different models with different levels of detail are used in the different simulation systems. It should be remembered that the synthetic environment appearance is not only visual, it can also apply to the appearance of a road in a CGF tool, where it is used for a navigation algorithm. In that case the appearance is not visual, but focused on the attributes that describe the characteristics of the road.

3. The operators should be able to **interact** similar with the synthetic environment. This includes the ability to open the door of a building in a similar way, but also includes the interaction of a vehicle mobility model with the soil characteristics as modelled in the synthetic environment. These interactions should be similar enough to ensure “fair fight” conditions.

These three aspects of correlation do not have to be considered for every element and everywhere in the synthetic environment. They are restricted by the following three contexts:

1. The context of the **mission** that is being simulated. For example, this restricts the area where correlation is required to the area where the mission is performed. If the distributed simulation is being used for a convoy protection mission, the correlation between the different simulation systems is only relevant for the area around the route of the convoy.

2. The **real-world operational** context, which means that correlation is only required if there would be correlation in the real-world operation as well. For example the fact that certain sensors show a black-and-white infrared image of the synthetic environment and therefore do not correlate with a color visual representation of that environment is not a correlation issue, but a correct representation of the real-world situation.

3. The **simulation application** context which specifies the aim for which the distributed simulation is used might also affect the correlation requirements. For example, a simulation where the aim is to train the correct application of procedures might have lower correlation requirements than a simulation with a mission rehearsal aim.

Figure 1 gives a graphical representation of these characteristics of correlation.

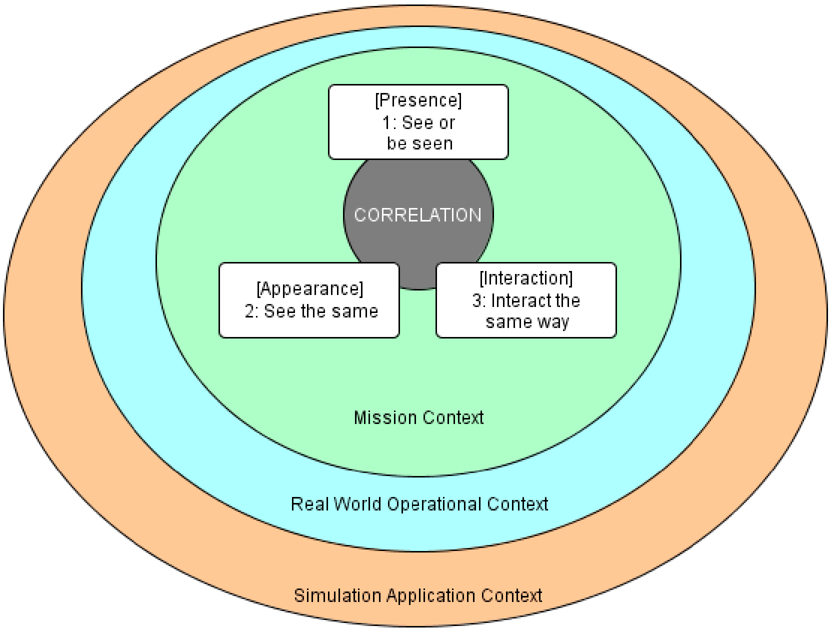

Figure 1: Correlation characteristics

3 Sources of correlation issues

To be able to effectively manage the required amount of correlation between synthetic environment representations it is important to have an understanding where correlation issues might be introduced during the design and development of the synthetic environment.

The SISO RIEDP [2] standard has defined a Reference Process Model for the production of synthetic environment databases. This process model is very useful when considering the possible sources of correlation issues. Figure 2 shows a graphical representation of this model, which has been annotated with the most common sources of correlation issues. These sources are:

1. **Different requirements** of the simulation systems, which results in different requirements of the synthetic environment as well. This source of correlation issues is difficult to solve, since the simulation systems each have their own requirements (for example, consider an infantry and a flight simulation again). On the other hand, when the decision is made to combine different simulation systems in a distributed simulation exercise, there should be sufficient overlap in their requirements to allow a successful simulation of the mission that they need to perform jointly.

2. **Different source data and content** are being used to develop the synthetic environment. Starting the production of the synthetic environment from different data will obviously increase the chance of correlation issues. That is why it is common practice already to start with a common dataset for the synthetic environment.

3. **Different processing** is applied when transforming the dataset into a runtime database. To reduce this source of correlation issues the processing should be done once for all the participants. This means that the common source dataset used by all the participants should reflect the state of the synthetic environment data after the processing has been applied. Examples of the processing are aligning data from different sources or deriving additional data.

4. At the end of the synthetic environment production process there are a number of steps that perform application specific processing on the data. The fact that different simulation systems can have **different application capabilities** can result in correlation issues. Since these are application dependent they are not so easy to address as the processing discussed in the previous bullet. Just as the different requirements, the influence of the different capabilities on the correlation of the synthetic environment has to be managed, in order to minimize the impact on correlation issues.

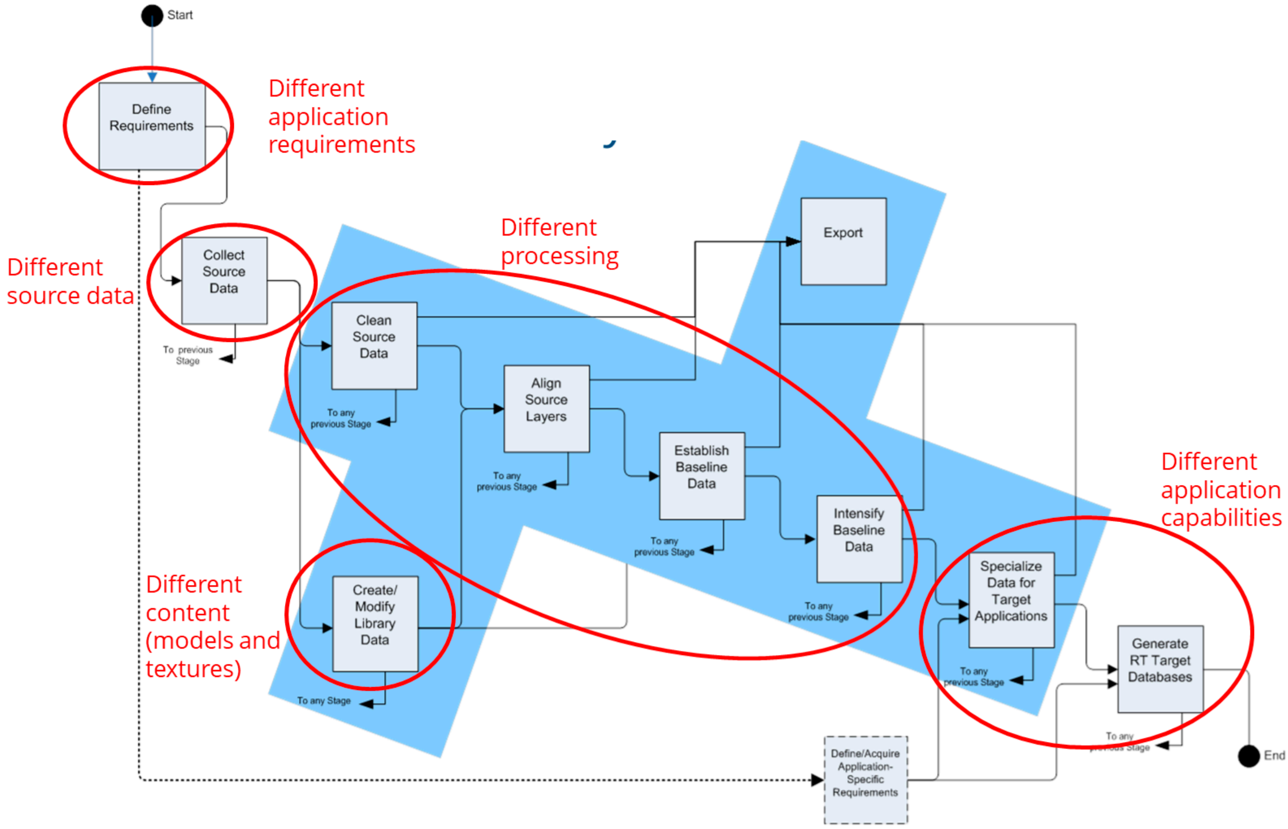

Figure 2: Sources of correlation issues in the synthetic environment production process (shown on the RIEDP Reference Process Model)

4 Process for managing correlation

Now that the characteristics of correlation and the sources of correlation issues have been discussed, the next topic is how to effectively manage correlation while setting up a distributed simulation exercise. In many of the current distributed simulation exercises correlation issues in the synthetic environment are only recognized and addressed relatively late in the development process of the exercise. It is not uncommon for such issues only to be recognized during the integration testing of the different simulation systems. But it is hard and costly to still address these issues that late in the development process. Therefore it is essential to include the synthetic environment correlation in the entire development process. The Distributed Simulation Engineering and Execution Process (DSEEP) [3] is a common process that is used for the development of distributed simulation exercises. In the remainder of this section reference will be made to activities from the DSEEP when discussing how correlation could be managed.

Figure 3 shows a graphical representation of the process to manage correlation of the synthetic environment, which will be discussed in the next sections.

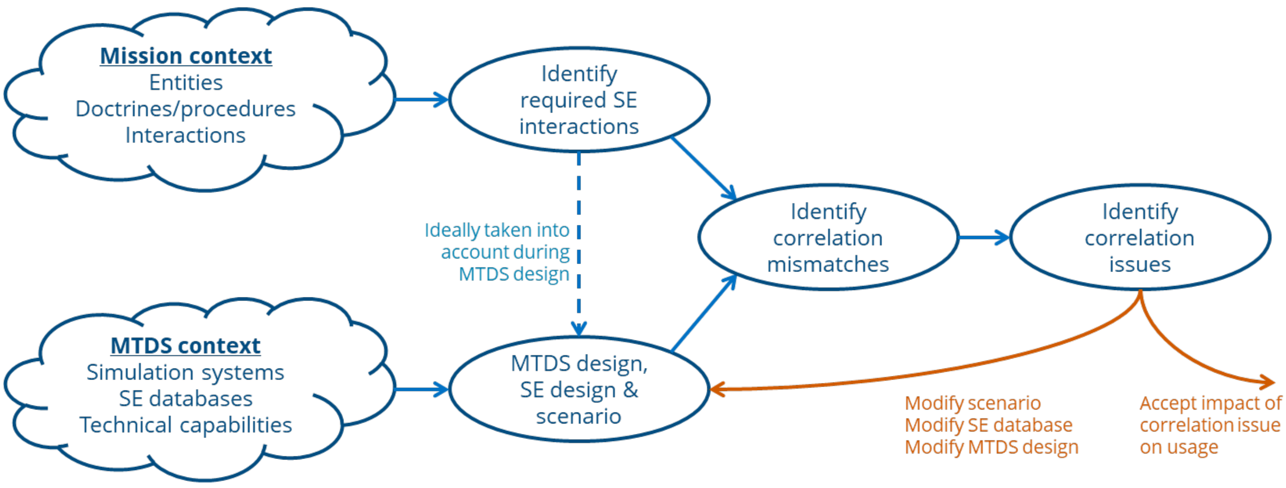

Figure 3: Process to manage synthetic environment correlation

4.1 Identify environment interactions

Correlation issues appear when different simulation systems represent the interactions between the operator and the synthetic environment differently. In order to be able to manage the correlation effectively, it is important to know which interactions with the environment are part of the real-world mission that is being simulated. This involves identifying which entities are involved, looking at the doctrines and procedures they use, and checking which interactions with the environment are needed. Such activities fall within the conceptual modelling phase of the DSEEP.

The DSEEP does however not specify in detail how the required interactions should be identified. We have looked at different approaches to identify these interactions with the environment. The most practical approach is to create an interaction diagram that shows how the involved entities, systems and environmental concepts interact with each other. Making such a diagram for a complex mission will however result in a big and hard to read interaction diagram. Therefore, we propose to divide the mission in separate blocks each considering one specific part of the

mission. That way the interaction block remains manageable in size. And it would also promote the reuse of existing interaction blocks and allow subject matter experts to create the diagrams for the aspect of the mission they have knowledge about.
For example, a Close Air Support (CAS) mission could be divided into blocks for:

- Target identification
- Radio communication between pilot and Joint Terminal Attack Controller (JTAC) team
- Weapon deployment against the target.

Figure 4 shows an interaction block for the target identification, describing which elements in the environment affect how two operators try to describe/identify a target using their sensors. The green boxes thereby represent elements of the terrain, while the blue elements represent elements of the weather. The arrows indicate interactions between elements represented in the simulation, the text clarifies the type of interaction that takes place.

When operators that are simulated in different systems interact with the same element in the environment, this identifies areas where correlation will be required. For example it could be the pilot of a fighter aircraft that uses his targeting pod to find a target, while a forward air controller is describing the target as he sees it with his eyes. The interaction block then shows that sufficient correlation is needed for the target and the way the atmospheric conditions, e.g. visibility, affect the target representation.

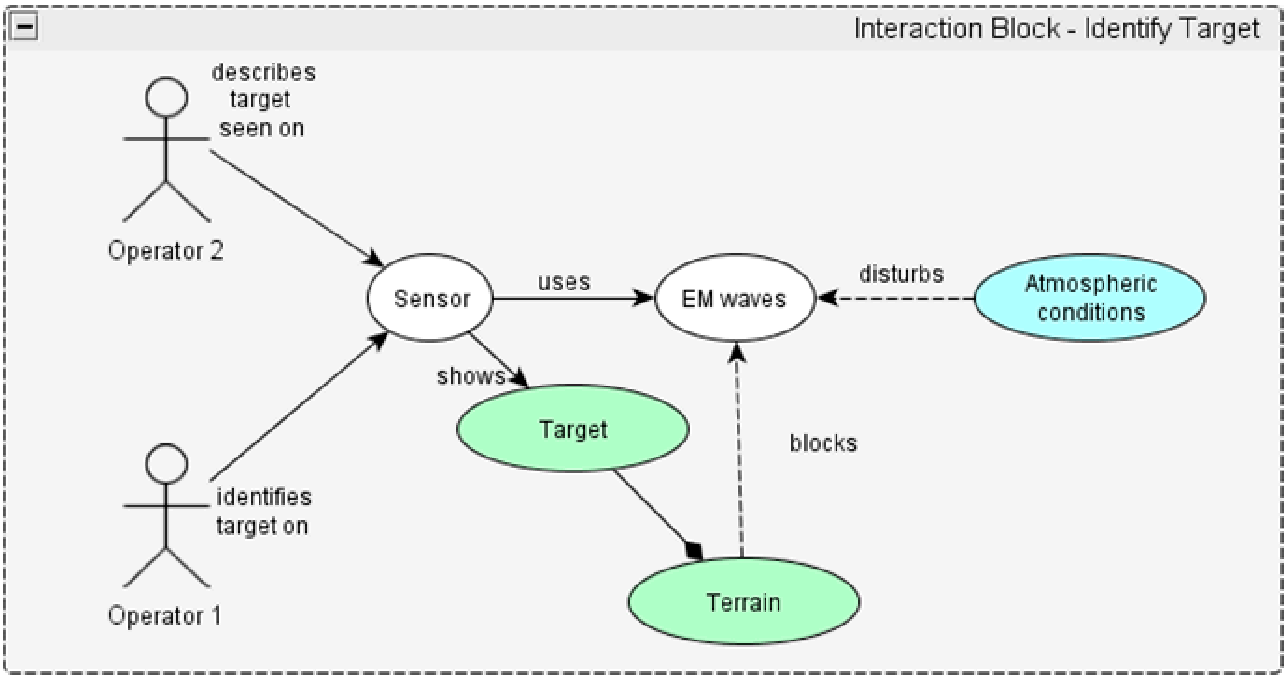

Figure 4: Example of interaction diagram with the synthetic environment

4.2 Identify correlation mismatches

Ideally the required interactions with the environment are taken into account when designing the distributed simulation exercise, for example when selecting the used simulation assets or when deciding on the used synthetic environment databases. But in reality, it is not uncommon that specific assets have already been selected or that these assets have their own synthetic environment databases that cannot be modified for the distributed simulation exercise.

Therefore, the next step is to check which of the required interactions with the environment can be performed with the designed distributed simulation. Especially the synthetic environment interactions that involve more than one simulation system within the distributed simulation are important to check, as those are the candidates for correlation issues. This results in a list of correlation mismatches. Checking of the interactions can be done at two levels:

1. A **'theoretical'** level where the requirements and design documents of the simulation systems and the synthetic environments are compared. This will give a high-level overview of areas where correlation issues are likely to occur.

2. A **'practical'** level where tests are performed to assess the synthetic environment representations for correlation mismatches. This can include comparing the different representations in a side-by-side view, sampling elevation values or checking line of sights in the different representations. The practical level checking will result in a more accurate list of correlation mismatches, but it is also more complex to execute.

Our advice is to use both approaches. The theoretical checking can be performed early in the development process of the distributed simulation exercise. It can be used to identify big issues early, when there are still sufficient possibilities to mitigate these mismatches, for example by changing the design. The practical checking can only be done when the actual simulation systems and synthetic environment databases are available. This is typically only later in the development process during the integration phase. At that moment the focus should be on checking the correlation for the most crucial aspects of the simulated mission.

4.3 Identify correlation issues

Once the correlation mismatches have been identified, the next step is to determine which of these mismatches are actual issues for the aim of the distributed simulation exercise. Given the definition of correlation, as formulated above, only correlation mismatches that affect the flow of the mission are an issue that should be addressed. Judging which correlation mismatches are issues, is an activity that is hard to capture in an algorithm, since there are many different aspects that should be considered. If the correlation mismatch is that certain elements are simply missing from one representation, it is rather easy to determine if this is an issue or not. But when it involves judging if two visual representations are similar enough to be interpreted the same, it becomes a lot harder.

Therefore it is foreseen that a subject matter expert (SME), somebody with enough knowledge of the operational mission, would have to decide which mismatches are problematic. In the future technological advances in the field of computer vision might be able to automate the process of determining whether the appearance of different synthetic environments is similar enough to be perceived the same.

4.4 Address correlation issues

What should be done with the correlation issues that have been identified? If possible one would go a step back in the development process and change either the scenario or the synthetic environment database or the simulation systems used to solve or reduce the correlation issue. If none of these are possible, the consequences of the correlation issue have to be accepted. In that case the instructors and white-cell operators have to be made aware of the present correlation issues.

5 New technologies and correlation

There are a number of recent technological advances that affect how the synthetic environment is being used within the simulation system and which also affect how we can manage correlation. In this chapter these technologies are discussed.

5.1 Run-time SE generation

To reduce the amount of time that is required to produce the synthetic environment there is a trend to perform (part of) the synthetic environment generation run-time in the simulation system. Traditionally the elevation data and imagery would be loaded into a database generation system which would create a 3D representation of the environment and store it in a runtime file format that the image generator can read. With run-time generation the image generator would read the imagery and elevation data directly. Creating the 3D representation from this data is then performed in run-time within the image generator process.

Since part of the synthetic environment generation is moved from the database generation system, where a human modeller can influence how the data is being processed, to the simulation system, where it is done automatically, this technology can potentially make it harder to achieve correlation between different representations of the environment. A lot depends on how configurable the run-time environment generation is.

Ideally the environment source data that is being used for the run-time synthetic environment generation comes with clear rules on how it should be represented in the simulation. This is similar to the rules that exist for the representation of geographical data on 2D maps, for which clear standards exist for (military) maps. The RIEDP Abstract Data Model (RADM), which is part of the RIEDP standard [2], is a promising candidate for a standard to specify these representation rules. The Detailed Feature Description part of the RIEDP standard is still in development. To be able to specify representation rules unambiguously using RIEDP, this part of the standard needs to contain the right amount of detail for the concepts and enumerations that are needed in the representation rules. This for example means that it should be possible to specify unambiguously how the elevation data should be flattened based on road vector data or how a 3D model of a building should be integrated in the terrain elevation mesh.

5.2 M&S as a Service

Modelling & Simulation as a Service (MSaaS) is a concept that allows simulation systems to become less monolithic and more modular by providing certain functionalities as a service, which can then be consumed by simulation systems [4]. In recent years MSaaS is seen as a concept that might help to reduce certain fair-fight issues in distributed simulation exercises.

Focusing on the synthetic environment representation MSaaS might be able to reduce correlation issues in the following ways:

- If the entire synthetic environment representation and visualisation is provided as a service, correlation issues could be fully solved. This would allow all simulation systems to consume the synthetic environment representation from one central source. Technically this is similar to cloud gaming technologies, where computer games are run on servers and the graphical output can be streamed to different devices. However, such a solution has a lot of impact on the architecture of simulation systems, which typically include their own image generator and other component to generate the synthetic environment representation. Although cloud gaming is starting to become more commonly used, it is not expected to be mature enough in the near future to be able to generate a synthetic environment representation with the update rates required for human-in-the-loop simulation systems. This could be a long term vision to eliminate correlation issues.

- An application of MSaaS concepts in the near future is using Terrain Servers and Weather Servers. All simulation systems can consume their environmental data from these common services. This would help to reduce correlation issues, especially if much of the processing on the synthetic environment data is also done on these servers. For example, the generation of building models from footprints could be performed in such a service, thereby ensuring a common representation of these buildings over different simulation systems. For simulation systems to be able to consume such service means that they need to be able to generate a synthetic environment representation on the fly from the received data, so this means that the run-time synthetic environment generation is an essential technology to be able to benefit for synthetic environment services.

5.3 Dynamic synthetic environment

The real-world environment is never static. It changes constantly due to weather conditions, for example the trafficability of an unpaved road changes due to heavy rain, or due to the effects of force engagements, for example combat engineering or damage to buildings due to weapon detonations. Until now, such dynamic changes in the environment are hard to represent in simulation systems. Certain standalone simulators support dynamic environments, but in a distributed simulation exercise it is almost impossible to introduce such dynamic effects in a consistent way.

By combining the possibilities offered by run-time synthetic environment generation and MSaaS concepts it becomes possible to introduce dynamic environments. Figure 5 shows this relation between the different technologies graphically. Changes to the environment can be made once in the central representation and MSaaS technologies can be used to let simulation systems consume this data. NATO MSG-156 “Correlated Dynamic Synthetic Environments for Distributed Simulation” is working on solution concepts that allow future distributed simulation exercises to use dynamic environments [5].

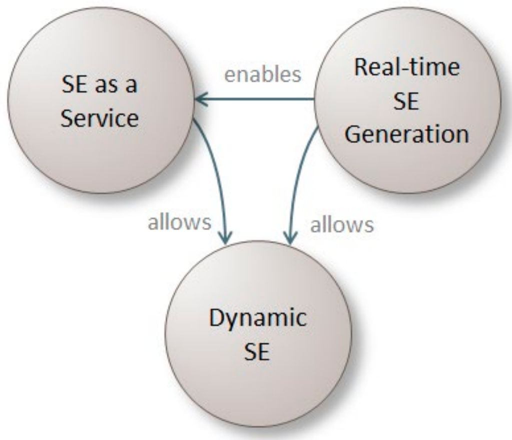

Figure 5: Relation between new technologies

Introducing time as the fourth dimension into the synthetic environment obviously makes it more challenging to ensure correlation between different simulation systems. It requires that these systems apply the changes to the environment in the same way and at the same moment in time. So, all of the possible correlation issues discussed so far are potentially enlarged by the introduction of dynamic changes.

However if the dynamic changes are introduced in such a way that they are applied on a central representation of the synthetic environment, this can be managed. This means that each simulation system cannot be responsible for its own environment representation anymore. This paradigm shift in the architecture of simulation systems is needed to be able to introduce dynamic environments in distributed simulation exercises without enlarging existing correlation challenges.

6 A correlation issue free future?

Do the technological developments and processes described before in this paper allow for a correlation issue free future? Unfortunately, the short answer to this question is no. For the foreseeable future, distributed simulation exercises will be performed with a mix of state-of-the-art and legacy simulation systems, simply because these simulation systems are available and need to be used in the joint and combined training exercise. This means that correlation issues in the distributed simulation exercises cannot be solved purely by technological solutions.

Therefore it is important that the synthetic environment correlation is an integral part of the development process of the exercise. Only when the required interactions with the environment are identified up front, they can be taken into account while designing the exercise. This also ensures that there are sufficient opportunities available to address correlation challenges when they are found. A process to handle synthetic environment correlation, as discussed in this paper, should be integrated into the development process used for the entire distributed simulation exercise. Tools and technologies to identify correlation mismatches between different synthetic environment representations are useful to support the identification of correlation mismatches. However, the final decision if a correlation mismatch is an actual issue is something that requires subject matter expert input.

When handling correlation during the development process it is important to have a realistic vision on correlation. The aim should not be 100% similarity between the participating simulation systems. Enough similarity to ensure the same flow of the simulated mission is sufficient.

For the longer term, the vision should be to change the paradigm of the synthetic environment representation so that correlation issues are reduced and new features like dynamic environments can be supported. Trying to do both with the current paradigm, where each simulation system is responsible for its own environment, is nearly impossible. By using MSaaS technology, a central synthetic environment service can be created. Dynamic changes to the environment only have to be made once in this central representation. The different simulation systems can consume the synthetic environment data from this service and need to use run-time synthetic environment generation technologies to create the representation of the environment. In this approach, there is a need for unambiguous representation rules of the synthetic environment data that is provided by the service. The SISO RIEDP standard looks like a promising standard that could be applied for this role in the future.

Looking even further into the future, the entire synthetic environment representation might be provided as a service, similar to the technology used for cloud gaming. But, given the high requirements on the synthetic environment representation for human-in-the-loop simulators it is not expected that such technology is mature enough in the near future.

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Dedicated to innovation in aerospace

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