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A NECESSARY PARADIGM CHANGE TO ENABLE COMPOSABLE CLOUD-BASED M&S SERVICES

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ABSTRACT

Cloud-based M&S can have many forms, from hardware as a service or cloud-based data for M&S applications to providing M&S as a service. In order to be able to compose such cloud-based M&S services, these services not only need to be able to exchange data and use such exchanged data, they also must represent truth consistently. Current paradigms are not sufficient to support these requirements. In this paper, a new paradigm is proposed that uses mobile propertied concepts to support consistent simulations using composable cloud-based M&S services. Mobile Propertied Agents (MPA) will utilize a floating middleware to establish an event-cloud orchestrated by a truth control layer. The result is a flexible Event Service Bus that ensure the consistent representation of truth in all systems connected to the event cloud, thus ensuring interoperability and composability by design in this cloud-based M&S environment.

1 INTRODUCTION

As described by Mohamed (2009), the ideas of cloud-based computing can be traced back several decades. As early as 1962, J.C.R. Licklider, who became a leader for the development of the Advanced Research Projects Agency Network (ARPANET) a couple of years later, worked on a series of memos on the concepts for an "intergalactic computer network" that would allow everyone to access programs and data from wherever they are and whatever device they were using. Since these early ideas, the Internet evolved significantly, but only in the nineties the bandwidth available to everyday users became large enough to support new ideas of distributed data and programs for every user, now under the idea of services. In 2002, the Amazon Web Services allowed to access storage and computation capabilities. They were followed by the Elastic Compute Cloud (EC2), a web service that provided small companies and individuals the option to rent computers in the Amazon cloud to run their own applications. The next big step happened when Google, Microsoft and others started to offer browser-based enterprise applications around 2009.

The Modeling and Simulation (M&S) community started to become interested in the use of these concepts in support of distributed simulation early on as well, as it is document in the archives of winter simulation conference paper. Examples are (Lorenz et al. 1997, Strassburger et al. 1998). A good overview of the discussions of that period is given by Page et al. (2000). The Extensible Modeling & Simulation Framework (XMSF) group formed by members from academia and industry conducted several experiments and developed prototypes to showcase the potential in particular for but not limited to the defense domain (Brutzman et al. 2002, Blais et al. 2005). Recently, Byrne, Heavey, and Byrne (2010) published a review of Web-based simulation and supporting tools showing the growing level of maturity of technical support. Calheiros et al. (2011) developed even a simulation system to simulate cloud computing. Nonetheless, the recent panel series on grand challenges of modeling and simulation sponsored by the Association of Computing Machinery (ACM) Special Interest Group of Simulation (SIGSIM) still identifies this topic as one of the unfinished tasks for research, in particular on the conceptual level (Taylor et al. 2012, 2013a, 2013b).

Johnson and Tolk (2013) point to recent work by the North Atlantic Treaty Organization (NATO) on the applicability of cloud-based simulation for their training exercises and other application domains. They identify five challenge perspectives that have to be addressed by solutions, which are the

- *Technical perspective* coping the selection of best technological solutions to implement M&S as a Service (MSaaS) and implement a cloud,
- *Governance perspective* dealing with challenges regarding how to distribute the responsibilities for updates and maintenance, administrative procedures, and other services needed to keep the cloud working and ready,
- *Security perspective* dealing with access privileges to ensure that every user has access to all services and systems he is eligible to use, but also to limit the access to only these services and systems,
- *Business model perspective* addressing the fair share of the burden for exercises including the maintenance during and between exercises, and
- *Conceptual perspective* making sure that only conceptually aligned solutions are selected, composed, and executed under the cloud as MSaaS.

In particular the work of Cayirci (Cayirci and Rong, 2011; Cayirci 2103a, 2013b) shows that the technical perspectives are well addressed by recent computer engineering developments and solutions can be applied in the context of cloud-based M&S. The recent paper of Malik, Park, and Fujimoto (2009) looked in some detail at performance issues for parallel and distributed simulation in a cloud. The many publications on cyber security show well that the security perspective is an ongoing challenge, but progress is being made. Governance and business model perspectives need to be supported by technical solutions, but are usually not a driver of current engineering research that are agnostic on underlying business drivers.

The focus of this paper is the conceptual perspective that is only insufficiently addressed in many publications with technical focus. While technical solutions are necessary, they are not sufficient, as conceptual problems are generally not solvable by technology alone. The special challenge for M&S interoperability was identified by Tolk (2013) as follows: Interoperability is defined as the ability to exchange data and use these data in the receiving system, which is enabled by technical solutions. However, each system represents in a model, a purposeful abstraction and simplification of a perception of reality represented using logic. While interoperability is necessary, the ultimate goal is the consistent representation of truth in all participating systems, which is the proposed definition for composability. The mathematical foundations for these propositions are given in (Tolk et al., 2013).

While simulations used for exercises and training may tolerate minor inconsistencies, other application domains, in particular analyses, require cause-effect-tracing via system border domains. The challenge addressed in this paper is: how can the consistent representation of truth in cloud-based environments be ensured? Virtualization of legacy solutions, such as envisioned for the Joint Live Virtual Constructive vision JLVC 2020 as described by Grom and Bowers (2012), are a significant technical step, but they do not address the conceptual challenge of misaligned conceptualizations without additional management processes.

The solution proposed here is a paradigm shift that uses mobile propertied agents who consistently represent the truth and align the data. They utilize a floating middleware to implement an event-service bus for the orchestration of events. M&S services are the functional leaves executing attribute changes on the mobile propertied agents and orchestrated by the event-service bus. It will be shown that this new view on distributed simulation overcomes the shortcoming identified in this introduction. Some of these underlying ideas already have been proven to be feasible and are applied in the context of cognitive method integration for training research in the US Air Force (Doyle and Portrey 2011).

2 BACKGROUND

Figure 1 shows the current concept of cloud computing: applications, platforms, and infrastructure are within a cloud that can be accessed via computer devices by the user. Solutions have to be virtualized for the cloud to maximize portability, manageability and compatibility. When software is virtualized, the software is encapsulated and separated from the original operation system code. This allows it to be executed in various computational environments. When hardware is virtualized, the hardware is abstracted to hide the physical characteristics from the user. The cloud brings virtual applications, virtual platforms, and virtual infrastructure together and maps them back to the real executable solution.

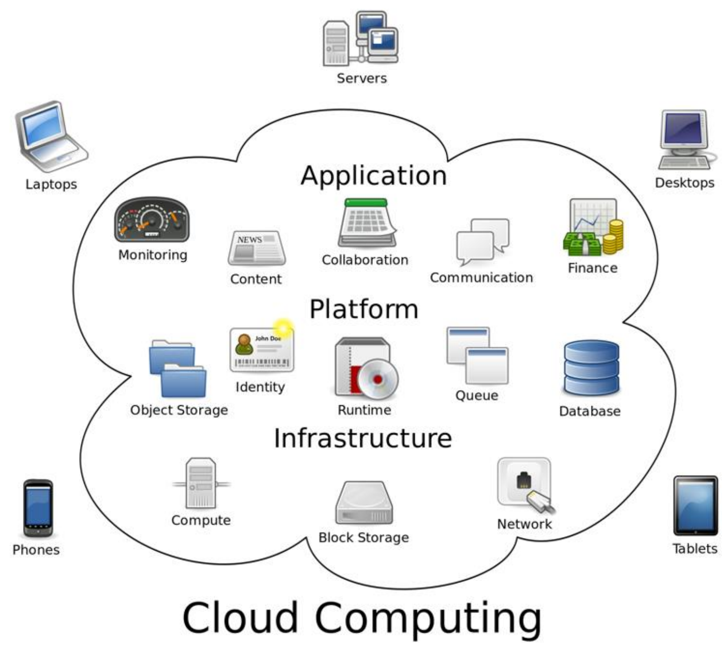

Figure 1: Cloud Computing (Courtesy of Wikimedia Commons).

Cloud-based M&S is mostly seen in the same context: simulation applications are virtualized, stored in a cloud, and now can be easy accessed from wherever a user is and whatever access device he uses. The technical difficulties for such an endeavor are not negligible, but virtualization of simulation applications is not sufficient to enable composable M&S services.

The idea of composable M&S services was discussed by Tolk et al. (2006) emphasizing the need for conceptual alignment of data and harmonization of processes. The principle idea is to have a set of services that provide functionality. Instead of having the collected functionality provided by a complete solution implemented in form of a simulation application, a user only has to use the functions he is interested in. Tolk et al. (2010) identify the following four general tasks:

1. *Identification* of applicable services, i.e., finding out which available simulation services can simulate a required entity, its effect or activities, and the result of such actions.
2. *Selection* of the best set of solutions, i.e., based on the customers problem decide which combination of the identified set of services is the best solution.
3. *Composition* of the selected services, i.e., engineering a solution that supports the information exchange required between the different simulation services (addressing what data need to be exchanged).

4. *Orchestration* of the execution, i.e., ensuring that the services are executed in the right order, that all data are available, that the data are available when they are needed, etc. (addressing when data need to be exchanged).

Each of the four tasks has its challenges. When identifying applicable solutions the engineer has to deal with homonyms and synonyms although by using a common namespace, such as provided by the National Information Exchange Model (NIEM), this task can be facilitated. Selection of the best solution must be done based on heuristics, as the problem itself has been shown to be NP-hard by Page, Briggs, and Tufarolo (2004). When services are composed, the data need to be aligned, as they can differ in scope, resolution, and structure (Moon and Hong 2013). When services are orchestrated, the challenge of temporal inconsistencies as already described by Reynolds, Natrajan, and Srinivasan (1997) needs to be solved.

Virtualization of simulation applications does not address any of these conceptual problems. The general challenges remain and have to be addressed. The crux of the matter is that the same concept is represented in different conceptualizations at the same time. The conceptual question to be answered is: Who owns the truth? Encapsulation may make matters even worse, as the different conceptualizations of the same concept may be hidden within the encapsulated solutions. How can we ensure the consistent representation of truth and enabled composable cloud-based M&S services?

3 PROBLEM DEFINTION

From the overview in the first section it becomes obvious that the main challenges on the conceptual level of the problem are the *alignment of data* and the *orchestration of processes*. This must ensure the *consistent representation of truth* in all supporting M&S services. Our approach addresses that technical challenges and proposes a solution.

Accordingly, this section describes various technical problems that need to be addressed in a parallel distributed cloud-based M&S. The list is enumerated in the form of questions as:

1. Who owns the simulation?
2. Who owns the state?
3. Who owns the shared, situated environment?
4. Who owns the knowledge or the truth?

LVC environment is one of the most complex environment that involves hardware, software and human operators engaged in an immersive battlefield experience. A typical LVC environment is a system-of-system where immersive experience emerges out of interaction between high-fidelity simulators, live assets and constructive entities in a live/virtual environment. The interaction is mostly handled by blackboard type architecture implemented using Distributed Interactive Simulation (DIS) protocol or subscribing High Level Architecture (HLA) Run Time Infrastructure (RTI) implementation. Cloud-based M&S on the other hand, is still in the nascent stage and presently using in a client-server paradigm wherein the simulator is deployed in a cloud and is accessed through services. Certainly, a lot of complexity can be hidden behind the Service interface. However, the lack of any shared memory system (such as DIS, HLA/RTI) or a communication medium that preserves the spacio-temporal nature of the common reality between various participants in a cloud environment prevents the Cloud-based M&S to be used for complex SoS M&S. This brings to light the age old issue of various silos (legacy systems with their own architectures that fail to interoperate) trying to interoperate. On a further note, no distributed simulation protocol implementation has been reported till date, that address various issue of parallel distributed simulation. Work by Mittal and Martin (2013a) towards a netcentric Discrete Event Systems (DEVS) Virtual Machine (VM) based on formal DEVS Systems Theory can be embedded in a cloud environment is one solution. This approach also bring various Domain Specific Languages (DSLs) to a netcentric environment. It implements a distributed simulation protocol, thereby preserving temporal relationships and integrates with Service-oriented architecture-based Event Driven Architectures (Mittal and Martin 2013b). This was also acknowledged as a preferred solution for realizing the potential of Cloud-based M&S (Zeigler, 2013). With Cloud-based M&S, syntactical interoperability is achieved as various standards are available in a netcentric environment. The low-level object communication subjected to implementation platform requirements has certainly been replaced by standardized message formats (using XML) that makes the platforms transparent. However, interoperability issues at higher levels (semantic, pragmatic, dynamic and conceptual) have not changed but are more amplified as each system is behind a Service interface and the assumptions that were considered during a systems development are hidden forever and not mentioned as such.

The second technical issue in Cloud-based M&S is the notion of system's state. Each federation in a distributed simulation maintains its own state. In a netcentric environment, the situation is no different: each system behind the Service interface maintains its own state. While the input/output interface of a federation (as a black-box) is clearly defined in a distributed simulation exercise, adding one more abstraction layer on the interface with the constraints of a netcentric environment redefines the implications of interface. A Service-oriented architecture (SOA) is primarily invocation-based i.e. an external agent requests a service from other agent, unlike a distributed simulation environment where events/message are pushed through a shared runtime infrastructure. It is unclear how the invocation-based mechanism maps to the black-box federated-design principles and if invocation results in inconsistent states at the Service provider's end. At a more in-depth level, the systems homomorphism (Zeigler 1976) has not been investigated. In SOA, at best the state is encapsulated in the message and is sent with the invocation request. This is the principle behind SOA-based Event Driven Architecture (EDA) (Taylor et.al 2009). Mittal and Martin (2103 a,b) elaborated on this issue and stated that as EDA is stateless, there is no notion of agency in EDA. It remains to be seen how a "system" or a "federate" with consistent states in a cloud-based environment comes to fruition.

The third technical issue that needs to be addressed with Cloud-based M&S is the issue of partial observability problem inherent in multi-agent systems (MAS). In MAS, the agents/systems interact with environment (with agents included) and one agent does not have a complete picture of the environment. Various solutions that have been implemented in MAS literature work under the assumption that the environment preserves its own sanctity and it is the agents that have different perspectives of the "same" environment. This assumption is shared and the changes in the environment are perceived with that assumption. With Cloud-based M&S, it is not clearly defined what the "environment" is and who controls it. With different realities in simulation systems behind Service interfaces, solutions available in MAS literature cannot be applied to solve this problem as the assumption of a shared environment falls.

The fourth technical issue that needs to be addressed is at the knowledge-level. The solution to the second issue is based on the premise that there is a corpus that defines what is contained in the environment. Whether that notion remains consistent across all the participant agents is the big question. In Cloud-based M&S, each system must also be willing to share the knowledge structure (implemented as standardized ontology). Knowledge-engineers and Subject Matter Experts (SMEs) have to ensure that the a concept defined in one ontology is truly the same concept that is shared across in a composable simulation. This is by far the most complex issue and may be the Achilles heel of Cloud-based M&S unless addressed upfront.

4 PROPOSED SOLUTION

The proposed solution is twofold. First, we introduce the concept of mobile propertied agents (MPA) to address the challenge of aligning data. Second, we introduce *concept-driven agent architecture* (CDAA) by way of an Event Cloud with a Truth Control Layer (TCL) that makes MPAs available to various federated services to address the challenge of orchestrating processes. Together, they can ensure the consistency of representation of truth.

4.1 Mobile Propertied Agents

A Mobile Propertied Agent is defined as an *agent that encapsulates a semantic concept, its associated properties* (by way of syntactic data elements) *and provides interfaces to manipulate the properties by external services*. In addition, an MPA contains a state-machine to record the current state of the encapsulated properties as it gets dynamically invoked by the external federates who want to use the particular semantic concept. The behavior of an MPA may be either discrete-event or discrete-time depending upon the larger infrastructure MPA is part of. Regardless, the objective behind MPA is to have a *state* that remains consistent and/or gets updated as it is accessed by different simulation federates. Discrete event foundation is the most likely case as managing global clock may be prohibitive in Cloud-based M&S. Within EDA, an MPA can maintain the standard Greenwich Mean Time (GMT) representation as the underlying enterprise cloud-based infrastructure has to be based on at least one Time Zone. Any invocation of an MPA results in an event and consequently, any property update within the MPA also results in an event. An MPA may also contain platform independent code (e.g. in XML) that gets executed at the external federate. However, this feature of code portability requires its due diligence and is left of future work. In advanced case of MPA design, the MPA will be under a supervisory control to implement and governance and security policies. An MPA facilitates semantic interoperability and implement ontological concepts that can maintain the state of their properties as they are accessed and utilized by external simulation federates.

From systems perspective, any system has a structure and behavior. In knowledge-based systems, there is an element of data/knowledge that is considered a part of the model. In our solution, we have separated the knowledge element by way of MPAs and cast the semantic concept as an agent with its own behavior. Consequently, a semantic concept is now, theoretically a *system* and being modular, can be integrated with other systems (external federates) in an enterprise context such as in Cloud.

An MPA is hosted within an Event Cloud infrastructure (e.g. Esper, TIBCO) in close conjunction with a controlling middleware that provides various transformers/adapters to enable invocation of an MPA by external federates using the Service Oriented Architecture (SOA).

MPAs ensure the consistent representation of truth regarding the challenges derived from the need to align the data. The solution is actually quite simple: instead of allowing multiple representations of the same concept at various places, each concept is represented by exactly one MPA. If a service is in need of the concept, it floats to the service. That the required MPAs are at the right place is taken care of by the underlying architecture that is described in the next section.

4.2 Concept-driven agent architecture (CDAA) with MPA Cloud

A Concept-driven agent architecture (CDAA) is an architecture for a multi-agent system (MAS) that is guided by the concepts that the agents utilize to perform their function. It is a system-of-system (SoS) wherein the concepts are modeled as MPAs interoperating with other systems in a netcentric environment. A parallel distributed Cloud-based M&S involving MPAs shall have the following components, as shown in Figure 2:

1. *Event cloud that hosts MPAs*: An event cloud is the central concept in an EDA. Architecturally speaking, it is a database turned upside down accessible through a specific event query language (EQL). This acts as a shared memory or blackboard for MPAs. Here various patterns and spacio-temporal relations can be defined that utilize knowledge within the MPAs and keep MPAs consistent. It can manage the lifecycle of an MPA.
2. *Truth Control Layer (TCL)*: This middleware ensures that MPA invocations remains consistent. It acts as a knowledge-broker in the semantic domain and interfaces between the Event cloud and simulation federates.
3. *Simulation coordinator*: This is a component that manages a simulation exercise. It deploys requirements, employs assets, executes the simulation, orchestrates the service composition and assemble the simulation results in various formats. It implements a simulation protocol (an algorithm) that manages time and preserves causality between various simulation federates.
4. *Simulation Services*: These are the simulation applications that are made available as services. They can very well be domain agnostic simulation engines or formal Systems Theory-based M&S

kernels (e.g. DEVSVM) that are engaged with the Simulation Coordinator through the simulation protocol. They manipulate the states of MPAs.

5. *Enterprise Service Bus(es)*: These buses interface between TCL and the participating federates. They implement various message transformers to align the ontology gaps.

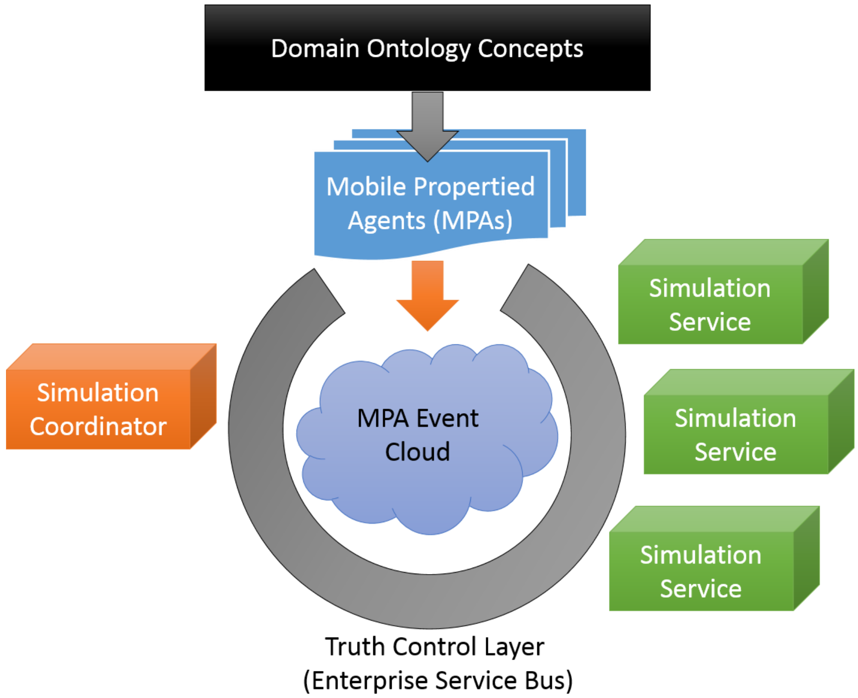

Figure 2: Concept-driven Agent Architecture (CDAA) with MPA Cloud.

As can be clearly seen, CDAA focuses more on the semantic interoperability and composability of MPAs towards a simulation solution in a Cloud-based M&S infrastructure.

All composable M&S cloud services are memory less, the required state information needed is provided by MPAs representing the participating concepts. While event cloud, TCL, and ES cooperate to bring the right MPAs to the simulation services, the simulation coordinator orchestrates that services are provided in the right order and at the right time, and as such ensures the consistent representation of truth regarding temporal and process orchestration challenges.

5 DISCUSSION

Using the floating middleware containing MPAs that implements the ESB ensuring consistency between the MPAs and the systems connected to the cloud addresses many of the challenges identified in the first sections of this paper, in particular the consistent representation of truth, but several problems still remain to be solved in future efforts.

First, although the proposed solution ensures consistency within the cloud, it does not solve the problem of ontology harmonization at the receiving part. If the system communicating with the cloud uses a model-based solution itself, the challenges of alignment of data and harmonization of processes address in this paper will have to be addressed again. Only conceptualization-agnostic access systems that simply display and control the MPAs in the cloud and that do not add another interpretation themselves will not create no challenges. In other words: Our proposed solution only ensures consistency in cloud-based M&S services that are based on the two principles of unique representations of concepts via MPAs and orchestration of all processes via the MPA Event Cloud. In the moment model-based solutions are integrated that have their own representation of concepts, the problems described by Tolk et al. (2013) are still existing.

The direct manipulation of internal properties of MPAs that is recommended in this paper seems to contradict the principle of the agent paradigm that allows for agents to decide how to react on a request for changes. In future developments this principle can actually be used in potentially inconsistent environments, i.e., environments that can create inconsistent requests for updates of internal properties. In such environments, an agent must be able to decide which request he grants and which he rejects. Important in the light of the proposal made in this paper, however, is that in any case the truth will be represented consistently by the MPA implementing the concept. If more than one MPA is needed to represent a composite concept, and there are additional constraints to be observed that rule the allowed property values in such a group of MPAs, this constitutes a whole new challenges beyond the scope of the current proposal. Maybe to ideas of Dignum, Dignum, and Joker who look at changes applied on the micro-level while their effects are controlled – or at least constraint – on the mesa level based on rules on the macro level can help to come up with good solutions for this general conceptual composition problem.

On the cognitive level, the knowledge encoded in the model-based solutions and its applicability to address the problem of the customer or support the task of the user can became a challenge in itself. Each simulation is implementing a model, and a model is a purposeful, task-driven simplification and abstraction of a perception of reality (Tolk 2013). As such, there can be no universal simulation solution. Instead, multi-model solutions are needed to address different conceptualizations, such as already envisioned by Yilmaz et al. (2007). To address this issue, it is necessary to educate M&S developers better regarding the epistemological foundations of simulation, as such conceptual challenges cannot be solved on the technical level.

In this paper, we do not address the challenge of time management in this proposed solution. We assume that proper time management services will be provided by the simulation coordinator and its implementation of the simulation protocol. Most of the proposed cloud-based simulation solutions assume real-time applications for training purposes (Cayirci 2013a, Gom and Bowers 2012). However, as MPAs are used to preserve the properties used to represent a concept, we could introduce an MPA describing time, or using properties within each MPA to describe time. This would even allow to model concepts like relativity and the simulation coordinator indeed has to be event-driven allowing a simulation engine based on abstract time. The abstract simulator and coordinator (Zeigler, 1976) are very much the requirements for the proposed architecture.

For the implementation of the ESB, several options provided by the industry can be used in support, as the M&S specific challenges are addressed by the MPA and the simulation coordinator. Erl's book on service-oriented design patterns is one example (2008). Chessel and Smith (2013) present design patterns that can be utilized in this context as well. Overall, many solutions that focus on the implementation level now become accessible to the M&S community at the full extend, as the conceptual challenges needed to be addressed to ensure the consistent representation of truth across the solution are dealt with in separated components.

The proposed solution is still in its infancy and leaves room for improvement, but it provides an answer to the challenge how we can ensure composability and make full use of recent technological advances while addressing the unique challenges of the M&S domain. Current new architecture research, such as described by Doyle and Portrey (2011, 2014), contributed not only to the development of these ideas, they also serve as a reference implementation proving the feasibility.

The main contribution of this paper is the *separation of representation of concepts* within the cloud-based services, which is not the case when current simulation systems are simply virtualized, *from the manipulation of properties representing the concepts* within cloud-based services. It addresses the identified conceptual challenges that have not been explicitly addressed in the cloud-based M&S literature so far: the alignment of data and the orchestration of processes to ensure a consistent representation of truth within the whole system.

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