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TOWARDS A GUIDE TO DOMAIN-SPECIFIC HYBRID SIMULATION

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ABSTRACT

The advantages of combined simulation techniques have been already frequently discussed and are well-covered by the recently published literature. In particular, many case studies have been presented solving similar domain-specific problems by different multi-paradigm simulation approaches. Moreover, a number of papers exist focusing on theoretical and conceptual aspects of hybrid simulation. However, it still remains a challenge to decide, whether combined methods are appropriate in certain situations and how they can be applied. Therefore, domain-specific user guides for multi-paradigm modeling are required combining general concepts and best practices to common steps. In this paper, we particularly outline three major processes targeting to define structured hybrid approaches in domain-specific contexts, and we focus on some practical issues aiming to a sustainable model development. Finally, an example hybrid methodology for problems in healthcare will be presented.

1 INTRODUCTION

Due to an increasing complexity of current models, many established simulation and modeling techniques are not sufficiently powerful to solve large-scaled problems solely. As stated by Zulkepli, Eldabi, and Mustafee (2012), using only discrete modeling methods can lead to an exponentially growing model complexity, and continuous approaches are not able to represent individuality. These limitations are a major reason why hybrid simulation modeling is receiving a growing attention in recent times. The main idea is to combine two or more different simulation paradigms aiming to take profits from the advantages of all applied methods. In particular, the Discrete-Event Simulation (DES), System Dynamics (SD), and the Agent-Based Simulation (ABS) are highly relevant techniques in this scope.

There is a vast body of academic papers discussing the applicability of the just mentioned simulation paradigms in certain domain-specific contexts. Most of them provide criteria to use the one or the other method to model a special case study. For example, Wakeland et al. (2004) published a comparison of System Dynamics and Agent-Based Simulation identifying an appropriate approach for a case study of cellular receptor dynamics. Parunak, Savit, and Riolo (1998) compared equation-based techniques to the ABS approach in light of supply networks applications. Another example has been presented by Tako and Robinson (2009). The authors discussed two implementations of the same problem using different simulation paradigms (DES and SD). In this case, differences in complexity and validity have been identified particularly. Brailsford, Churilov, and Liew (2003) evaluated DES and SD techniques within the scope of emergency department simulations. Accordingly, both methods have their individual advantages, but there are also limitations that have to be considered. Therefore, the authors suggested to build integrated models using more than one single technique. Many multi-paradigm examples and case studies have been presented until now solving specific problems in different domains. For example, Endrerud, Liyanage, and Keseric (2014) used ABS in combination with DES to evaluate scenarios for marine logistics of offshore wind

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parks. Feng and Fan (2014) applied the same simulation paradigms to model case studies for workforce planning of production lines. There are several further examples using hybrid simulation in healthcare. For example, Zulkepli, Eldabi, and Mustafee (2012) applied DES and SD in a hybrid simulation context to develop an integrated care model. Djanatliev and German (2013b) used SD, ABS and DES to evaluate innovative healthcare technologies prospectively, e.g., Mobile Stroke Units (Djanatliev et al. 2014). The same three simulation paradigms have been applied by Viana et al. (2012) in a case study focusing on age-related macular degeneration. An example overview of papers applying different techniques in healthcare can be found in Abdelghany and Eltawil (2014). Another appropriate literature review and a methodical overview have been presented by Powell and Mustafee (2014). There are also some further papers focusing on theoretical, philosophical, or methodological aspects of hybrid simulation. An example article therefore has been authored by Brailsford, Desai, and Viana (2010). This paper discusses the idea of hybrid simulation on the way towards the "holy grail" which represents an ultimate goal to combine genuinely different views on a system. In particular, the authors presented two healthcare case studies, and they stated that both examples could be modeled by the application of only one single simulation paradigm. However, this task is comparable to a situation of "hammering in a screw". Generally speaking, hybrid simulation helps to build models in a flexible and straightforward manner.

Although a lot of significant work can be found, it still remains a challenge to decide, whether hybrid simulation is appropriate in a certain situation and how this approach can be applied to solve an existing problem. In particular, best modeling practices that have been implemented in previous case studies remain not visible from a methodical point of view for other similar use-cases. Otherwise, promising theoretical concepts are rarely applied in actual case studies due to lacking practical examples. Hence, when developing hybrid scenarios the modeler typically starts from the scratch, and uses "only" its own modeling experience at the beginning of a new hybrid simulation project. In order to be more efficient it is preferable to reuse agreed best practices in further case studies of the same domain and it is important to provide dedicated application steps for theoretical concepts. In other words, practical and theoretical aspects must be mapped to each other by domain-specific modeling guidelines.

In this paper, we particularly outline three major processes which are important to define a specialized hybrid approach in domain-specific contexts. Most important concepts will be explained using an example hybrid simulation definition for prospective healthcare decision-support. Furthermore, we focus on practical issues aiming to sustainable model developments (e.g., tooling, framework building).

2 RELATED WORK

Probably the most related publications to this paper have been published by Chahal and Eldabi (2008), and Chahal (2009). The authors presented a conceptual framework for hybrid modeling in healthcare. In particular, DES and SD have been applied to support policy-makers from a strategic and an operational perspective. The papers outline the following sequence of essential steps targeting to build hybrid models by a well-defined procedure: (1) problem identification and justification to use hybrid approaches, (2) mapping between System Dynamics and Discrete-Event Simulation, and (3) identification of a mode of interaction for the models.

In particular, the publications introduced three frequently referenced modes (or formats) for hybrid modeling which can be seen as most fundamentally when referring to hybrid simulation. The *hierarchical format (HF)* combines SD models and DES models just by passing data from one model to the other. In this case, SD will be used at a strategic level and DES can be applied to model structures at an operational level. According to the *process environment format (PEF)* a certain process can be modeled by DES, but SD can be particularly used to model a surrounding environment of the process. Finally, the integrated format (IF) targets to a completely integrated hybrid model without actual paradigm distinctions. This is probably the previously referenced ultimate goal of hybrid modeling, or the "holy grail" in words of Brailsford, Desai, and Viana (2010) that has not been achieved yet.

Another related paper has been presented by Heath et al. (2011). It was accompanied by an interesting panel discussion at the Winter Simulation Conference 2011 referring to several challenges and successes of cross-paradigm modeling. The authors compared all three simulation paradigms, namely DES, SD, and ABS. All possible pairs (SD vs. DES, SD vs. ABS, DES vs. ABS) have been considered in detail discussing advantages and possible pitfalls. Furthermore, a differentiation of two different world-views for DES has been presented; a classical event-oriented world-view and a process-oriented DES world-view. Finally, an overview of available software packages is given and their evaluation in light of hybrid simulation. Accordingly, there are many tools that are primarily following one modeling paradigm and provide extension features for other techniques. However, few software packages with fully integrated hybrid modeling functionality exist as well.

3 DEFINITION OF A DOMAIN-SPECIFIC HYBRID SIMULATION APPROACH

It has been frequently stated that the hybrid methodology is not precisely defined yet (e.g., Heath et al. 2011), so that many different meanings exist in the published literature. Most recently, Balaban, Hester, and Diallo (2014) discussed this problem and proposed own formal explanations for selected terms. In our previously published work, we also identified a necessity to define common terms (see Djanatliev and German 2013b). In particular, we tried to clarify the meaning of *hybrid simulation* and *multi-paradigm modeling*. Both are aiming to combine modeling techniques, but we suggested to use the term *hybrid simulation*, if a distinction between continuous and discrete methods is particularly referenced. However, to avoid misunderstandings we use both terms interchangeably in this paper.

As previously mentioned, there are several case studies applying different hybrid methods to solve similar problems, as each modeler starts modeling from the scratch and doesn't use best practices from other examples. This variability in hybrid modeling is probably one reason why the applicability of hybrid simulation is still complex. Furthermore, diverse methodological papers exist presenting concepts that only rarely have been applied in actual use-cases due to a lacking practicality. In order to tackle this problem, best practices from applied case studies can be identified and transferred to a general methodological level. Appropriate modeling guidelines explaining in which situations certain concepts can be applied help to develop a common hybrid modeling approach. However, we experienced that it is not easy to define a general and generic hybrid simulation method for all possible application areas. Though a lot of best practices can be applied in studies of different domains, most essential concepts remain domain-specific. Therefore, modeling guidelines are important to reach a structured procedure for similar modeling issues in a certain application area.

3.1 Methodological Overview

In particular, three major processes are essential to structure the scope covered by a certain domain. First of all, independent levels of abstraction, views on a system, or subclasses of the considered domain must be identified (step 1). For instance, this can be achieved by a consideration of smaller problem areas represented by available case studies (e.g., hospital simulations, epidemiological models). As a next step, simulation paradigms have to be linked to the previously described abstraction levels (or subclasses) explaining how they can be deployed to represent typical situations (e.g., affection processes) at the referenced level (step 2). In this case, concrete implementation scenarios must be defined and explanations have to be given describing how to use a certain simulation paradigm to model structures at the considered level (e.g., incidence rates are used in SD models). We call this process of coupling between abstraction levels and simulation paradigms *horizontal paradigm linking*. Thereafter, as a final step a third twofold process must be applied (step 3). It describes on the one hand a connection between the identified subclasses (i.e., interactions between abstraction levels), on the other hand it must be defined how paradigm-related elements can be connected to each other, or how interactions between SD, DES, and ABS can be realized. This process is called *vertical linking of simulation paradigms*.

Figure 1 gives a compact overview of the two latter described processes. On the left hand side relevant abstraction levels or subclasses are depicted, while on the right hand side applied simulation paradigms are referenced. The connection between simulation paradigms and abstraction levels is particularly illustrated in the central part of the figure. The two blue arrows are representing the connection between the abstraction levels, and the coupling of applied simulation paradigms. The consistency of a model and the representation of the truth can be achieved by the composability of system's components. That means it should be possible to combine different subclasses in different ways to solve various problems in this application area. Otherwise, the interoperability can be particularly mapped to the data exchange between different simulation paradigms (e.g., generating agents for the ABS from SD models). Further insights to composability and interoperability can be found in Tolk (2013).

Common and structured concepts for similar classes of problems help to achieve a sustainable and straightforward model development. In particular, they help to benefit from available solutions and to validate complex models referring to already pre-validated methods and best practices. When defining a new case study the most relevant abstraction levels can be selected first. On this basis one single simulation method or a set of simulation paradigms (hybrid simulation) can be identified for a problem, instead of thinking whether hybrid simulation is appropriate or not.

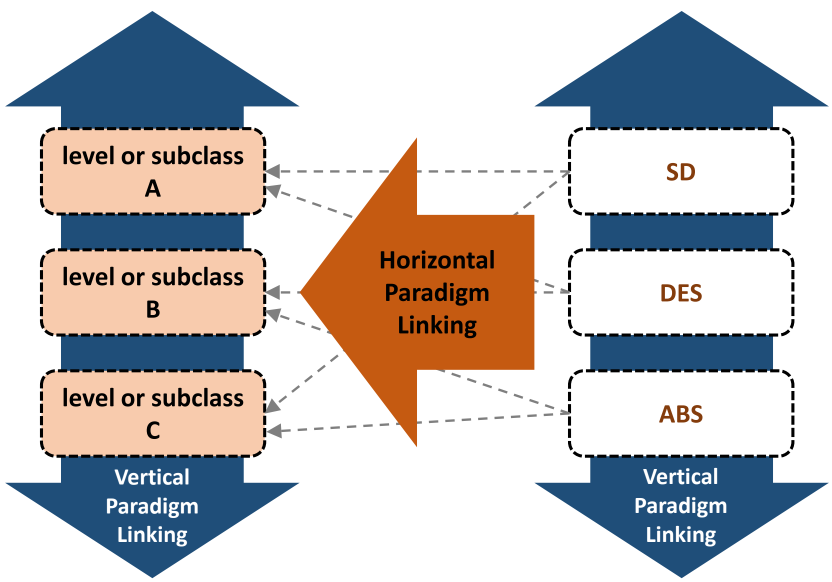

Figure 1: Two major processes to define a domain-specific hybrid simulation approach; horizontal paradigm linking and vertical paradigm linking.

3.2 Identification of Levels of Abstraction (Step 1)

As previously mentioned, it is necessary to identify independent problem areas within the considered domain, before thinking about simulation paradigms. There are many possibilities to perform this task. For example, it can be achieved by a division of the overall domain scope in specific subclasses where independent simulations can be implemented. In healthcare we can use a population, disease, post-disease, and economics subarea for instance. Another possibility is the distinction of intervention phases (i.e., prevention, pre-treatment, treatment, post-treatment). More generally, it is possible to use abstraction levels for a domain (e.g., macro, meso, micro). In case of the energy domain, a hierarchical breakdown into a country (macro level), city (meso level), house (meso/micro level), and a room (micro level) subclass is imaginable to cover most important situations within this context.

3.3 General Aspects of the Horizontal Paradigm Linking (Step 2)

Many papers are generally stating that SD is appropriate at holistic levels and discrete elements describe microscopic structures particularly. Though it might be true in several situations, there are also many examples where SD can be applied at the micro-level as well, and DES is appropriate to be used at high abstraction levels (i.e., to perform data updates annually). This is why the horizontal paradigm linking is a very important step. It particularly depends on the actual application domain which simulation paradigm can be applied at which level.

The main task is to determine whether continuous structures are relevant (i.e., SD), processes have to be traversed (i.e., DES), or an individual behavior is necessary (i.e., ABS). For example, in energy simulations SD elements can be used to represent energy flows at lower levels, and discrete events are relevant to model global control mechanisms affecting these flows (e.g., deactivating power plants). Furthermore, modeling of agents' behavior by continuous elements is also a typical example of using SD at low abstraction levels. In section 3.7 we describe an example hybrid simulation approach for prospective healthcare decision-support using the just presented processes.

3.4 General Aspects of the Vertical Paradigm Linking (Step 3)

As stated, this third step is used to to define interactions and data exchange between applied simulation paradigms. In the following we primarily focus on general aspects of the vertical paradigm linking, and on some selected best practices aiming to combine simulation paradigms. First, we describe five general interaction types between continuous and discrete structures. Thereafter, we focus on a mechanism to generate agents from SD environments.

3.4.1 Interaction Types Between Continuous and Discrete Structures

In general, there are two relevant methods enabling to connect simulation techniques. Chahal (2009) reported the difference between cyclic and parallel interactions. Accordingly, it is possible to develop models that are running independently and the output metrics from the one model can be used as input parameters for the other one. Another possibility is to build fully integrated models where different simulation paradigms are applied in a common simulation environment using the same time and space attributes. In particular, when referring to this lastly mentioned concept, direct interactions between continuous and discrete techniques are highly relevant. Continuous flows are usually changing values at very small time steps synchronously. In contrast, discrete events typically occur asynchronously. As presented in Figure 2, we basically distinct between five different interaction types.

First of all, continuous variables can be changed instantly by discrete events (*type e1*). The second interaction type refers to cyclic events (e.g., annual events) that can lead to changes in continuous structures as well as in discrete parts of the model (*type e2*). Predefined threshold values can be used to perform modifications in discrete structures due to changes of certain continuous variables. More precisely, it is possible to trigger an event when a maximum value has been reached (*type e3*), or if a value falls below a minimal limit (*type e4*). Finally, discrete simulation parts can read continuous variables to use their values in discrete structures just at the time when they are required (*type e5*).

3.4.2 Generating Entities, or Agents From SD Environments

In Djanatliev and German (2013b) another method has been presented that allows to couple SD with DES, or ABS. In particular, instances for the process-oriented DES, or agents for ABS structures can be dynamically generated from SD environments. As long as a microscopic perspective is not absolutely necessary, individuals can be represented in aggregated values of SD-stocks. If a more detailed evaluation is required, entities can be generated, e.g., to traverse process flows. Moreover, agents can be created dynamically, if an individual (active) behavior is necessary. Generally speaking, this approach is a special

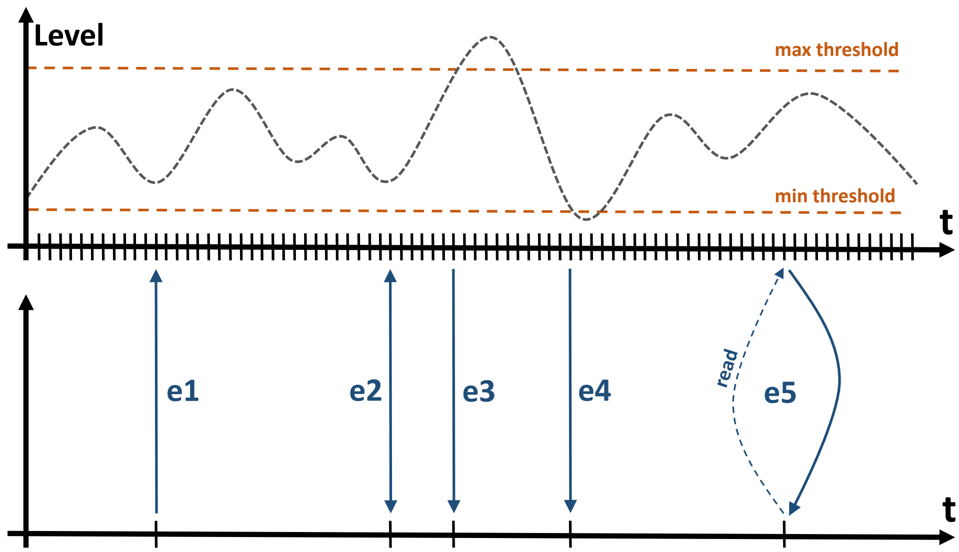

Figure 2: Illustration of the most essential interaction methods between continuous and discrete structures represented by the events e1-e5.

type of the vertical paradigm linking, or a best practice that can be applied in hybrid models. Obviously, it is imaginable to use this technique in models and case studies from different domains.

In practice, we distinct between an *observation time interval* and a succeeding *generation time interval*; both having the same length. During the observation phase a stock will be filled continuously. At the end of the interval a pick-up event triggers a generation of individual instances. In order to avoid a heapwise generation of individuals, new dynamic events can be scheduled for each instance to distribute the actual creation of instances within the subsequent generation time interval. Diverse distribution functions can be applied to perform this task, but most commonly a unified distribution is used.

3.5 Selected Design Issues

When combining different simulation paradigms two different world designs are often imaginable. As just presented, we can calculate numbers of individuals in abstract structures (e.g., in SD stocks). When generating individuals (e.g., entities for DES, or agents for ABS) it is possible to keep these numbers unchanged, so that an individual will be represented in both structures separately (*parallel world design*). This is probably relevant in situations where entities or agents are generated only for a short time period temporarily to perform a certain task (e.g., traversing processes). Another possibility is to adjust the corresponding values of SD-stocks after individuals have been generated. In this case, the stock value and the number of generated individuals are representing the actual population value together (*one world design*).

A further design issue is the modeling procedure itself. The bottom-up approach allows to start modeling at a very detailed abstraction level (e.g., ABS). In this case, a modeler aims to represent the reality as exact as possible and aggregates micro elements to represent a holistic level. Hence, this method particularly uses microscopic models as main simulation environments and applies generalization techniques to aggregate only relevant elements. There is a major drawback in large-scale simulations. In particular, a lot of useless details for a certain case study will be represented and high data requirements must be met. Probably a more appropriate way is to apply the top-down approach. In this case, an environment is modeled at the holistic level (e.g., by SD) and one goes in detail to represent an important microscopic issue. Hence, details will be only modeled, if they are actually required and just relevant data will be used. This approach can be combined together with the previously presented Process Environment Format (Chahal and Eldabi 2008), but it is not necessarily to use DES to model the simulation core.

3.6 Aggregating Individuals in Containers or by Statistics

Diverse advanced methods can be applied to achieve a better simulation performance. For example, performing parallel and distributed simulation runs. Moreover, there are many situations where individuals are not required at a very low level. Therefore, *superagents* can be used to represent several individuals with a similar behavior. Instead of performing equal calculations for each agent, set routines can be performed and all individuals are following a common behavior. For example, common annual processes (e.g., aging), traversing of common workflows, or calculations of costs based on disability classes.

Figure 3 illustrates two different strategies that are particularly relevant at this point. The container concept collects individual agents in a common superagent. The agents still exist, but their behavior state charts are "paused" in order to follow the processes of a common superagent. If required, they will be removed from the superagent and reactivated to act alone. Another possibility is to use statistics representing all containing individuals inside a superagent. In this case the joining agent instances will be deleted after they have been considered in the statistics. As presented, a unique agent can be sampled from the statistics to run alone. In this case, the corresponding statistical values must be adjusted.

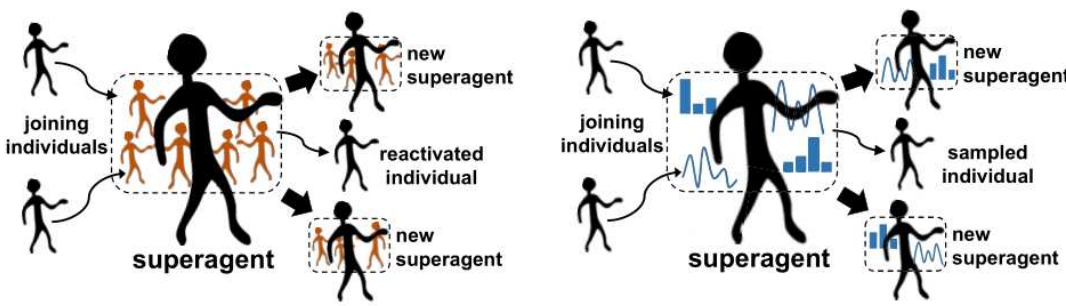

Figure 3: Two representations for a superagent. Combining agents in containers (on the left hand side), or using statistics to represent the containing population (on the right hand side).

3.7 Example: Prospective Healthcare Decision-Support

In Djanatliev et al. (2014) we presented two central question types aiming to evaluate healthcare technologies prospectively. Accordingly, it is possible to assess existing product ideas by hybrid simulation regarding the medical and economic perspectives. Optimizations and improvements can be performed prior to the cost-intensive product development. The second question type enables to evaluate existing structures in order to detect weaknesses and to find bottlenecks. As a result, a new hypothetical technology can be designed that is able to solve the detected problems.

In this scope we finally processed four case studies. In particular, a new specialized vehicle for stroke treatments has been evaluated (see Djanatliev et al. 2014), a hypothetical bio-marker has been defined that can reduce over-treatments improving prostate cancer screenings, and finally two further case studies have been executed (e.g., cardiology). Based on the three previously presented processes, we defined a hybrid approach for simulations in this context. One of the first version has been already published in Djanatliev and German (2013b). The last version is depicted in Figure 4. It shows schematically the most important aspects including the relevant abstraction levels, the horizontal paradigm linking, and the vertical paradigm linking. In the central part illustrations of possible interactions are presented.

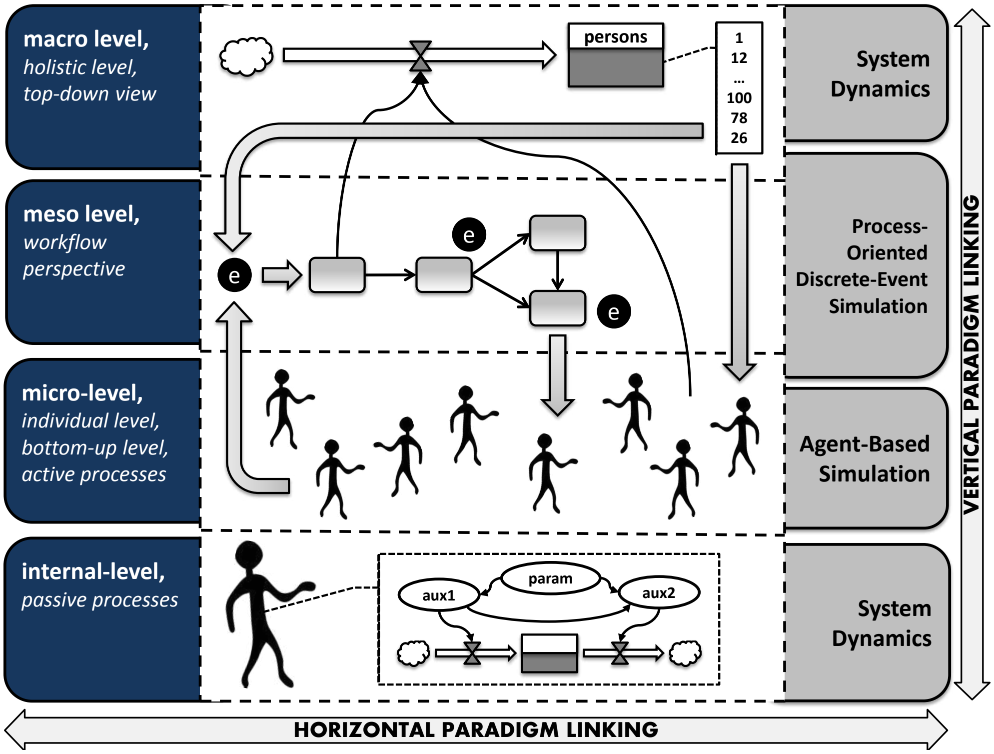

Figure 4: Overview of our hybrid simulation approach for prospective healthcare decision-support.

3.7.1 Horizontal Paradigm Linking

Decision-makers are faced with a lot of complex problems at high abstraction levels and such at low abstraction levels. Therefore, we particularly identified four different levels in the context of healthcare decision-support, namely the macro-level, the meso-level, the micro-level, and finally, the internal level.

At the macro-level global structures can be represented including the demographic and epidemiological changes. Furthermore, economic and budget-focused evaluations can be performed (i.e., Budget Impact Analyses (BIA)). System Dynamics is particularly appropriate to represent those coherences. However, minor DES techniques can be applied to perform input data updates.

The meso-level is particularly representing workflows (i.e., hospital processes), and allows to model clinical pathways. In one of the previous version we used ABS state charts to model such structures, however it resulted in nontrivial models containing replicated workflows. Therefore, we currently apply the process-oriented Discrete-Event-Simulation. In this case, entities (without an individual behavior) are traversing paths and are changing global structures (vertical paradigm linking).

At the micro-level more detailed structures can be represented. In particular, an active behavior of persons (e.g., patients) can be modeled comfortably. Active behavior include primarily actions that have been initiated by the agent explicitly (e.g., taking medication, calling the doctor). At this level particularly ABS can be applied.

Finally, the internal-level represents very special situations. While the behavior of agents must be active at the micro-level, it is usually passive at the internal-level. Hence, it can be used to represent non-visible background processes inside the person's body. For example, arising movement restrictions and disabilities can be modeled at this level. In most cases such processes are very complex and rarely described properly in literature. Thus, we are using SD to represent such models. A representative example has been presented by Viana et al. (2012). In this case, each agent contains a pair of SD models representing the sight level of each eye. In general, such processes can be affected by the active behavior (e.g., taking medication) and they affect other structures as well (vertical paradigm linking).

3.7.2 Vertical Paradigm Linking

The vertical paradigm linking between SD, DES, and ABS is well represented by the previously described interactions between continuous and discrete structures. In particular, the domain-specific part of this process is located at the left hand side of Figure 1. For example, interactions between the macro-level and the meso-level can be achieved by changes of workflows (e.g., hospital processes). They particularly can affect global structures (e.g., reduced mortality). Similarly, changes at the global level can affect DES processes. For example, lacking resources due to an increasing incidence.

If focusing on interactions between the micro-level and the meso-level, agents can be converted to entities in order to traverse workflows. In this case a temporarily health record will be added to the object. After finishing a process, the agent's attributes will be adjusted due to the information contained in the health record. As previously mentioned, active processes can affect the passive behavior at the internal-level and vice versa. For example, taking medications can slow down a worsening process, otherwise a growing disability influences the active behavior at the micro-level.

4 RELEVANT SOFTWARE AND IMPLEMENTATION-SPECIFIC ASPECTS

Diverse simulation tools are available enabling to develop hybrid simulation models. In particular, Heath et al. (2011) discussed the applicability of existing software packages in light of hybrid modeling. Accordingly, there are tools focusing on one simulation paradigm providing extension features for other techniques, and there is AnyLogic (AnyLogic 2015). It is still the one software package that provides multi-paradigm modeling techniques in a common tool. Moreover, it gives the possibility to extend models by own Java-code making the modeling process more powerful and flexible. Most recently, Viana (2014) published a comparison to use AnyLogic, or to combine two different tools; one for System Dynamics (e.g., Vensim 2015) and the other for Discrete-Event-Simulation (e.g., SIMUL8 2015).

In our simulations, we particularly prefer to use the commercial software package AnyLogic. Several implementation-specific concepts within the context of prospective healthcare decision-support have been previously introduced in Djanatliev and German (2013a). In particular, to achieve a sustainable model development by the application of agreed best practices, we call for framework building and domain-specific libraries. At this point AnyLogic offers flexible library building features. Hence, it is possible to develop own components and to collect them in common libraries. As presented in Djanatliev, Bazan, and German (2014), we developed the *HealthDS Framework* to build scenarios within the scope of healthcare decision-support. This framework contains among others reusable modules for demographic and epidemiological structures at a high abstraction level. Furthermore, components are available to build more detailed scenarios, e.g., hospitals, rescue vehicles, geographic features etc. Moreover, we also presented another component-oriented framework for energy simulations, namely the *i7-AnyEnergy*.

5 CONCLUSIONS

To take profits from combined simulation techniques it is important to decide whether hybrid simulation is required for a case study and how it can be applied to solve a special problem. As there are not agreed steps and guidelines to develop such models, many modelers are usually processing each project from the scratch. Therefore, applied best practices are not visible for other modelers. Otherwise, many theoretical concepts are not used due to a lacking practicability. Hence, known best practices and theoretical methods must be mapped to each other defining common modeling guidelines. However, it is not easy to work-out common steps for all possible application areas. Therefore, the following three processes have been introduced in this work aiming to define a domain-specific hybrid simulation approach:

- **Step 1:** Identification of relevant levels of abstraction or subclasses.
- **Step 2:** Horizontal paradigm linking.
- **Step 3:** Vertical paradigm linking

In particular, the horizontal paradigm linking considers the mapping of simulation paradigms to typical situations covered by the considered domain (e.g., SD for energy flows, DES for hospital workflows, SD for the affection process). In contrast, the vertical paradigm linking describes interactions and data exchange between simulation paradigms (interoperability) and the composability of abstraction levels and subclasses. In this paper we presented five most relevant types of interaction between continuous and discrete structures. Furthermore, we discussed selected best practices (e.g., generation of agents from SD environments) and relevant design issues. Finally, an example in healthcare has been presented applying all three steps to define a specific hybrid simulation approach. Within the last part we outlined the possibility to combine paradigm-specific tools, or to use AnyLogic (AnyLogic 2015) which is the only tool for multi-method modeling until now. In particular, we highlighted library features of this tool enabling to develop own domain-specific frameworks and libraries with reusable components.

At the beginning of this paper we posed two questions targeting to decide, whether hybrid simulation is appropriate to solve problems in certain situations, and how it can be applied. Thus, when using a common domain-specific hybrid simulation approach, it gets simpler to cover both initial questions. If a problem can be matched by one level, and only one simulation method is mapped to this, a single paradigm modeling is sufficient in this context. However, if more than one method is mapped to the levels covered by a certain problem, then a hybrid approach is highly relevant. Due to the vertical paradigm linking interactions and predefined typical situations can be used to apply the hybrid simulation in order to solve a certain problem.

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