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Introductory Chapter: Simulation and Modeling

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1. Introduction

The influx of data in the world today needs analysis that no method can handle. Some reports estimated the influx of data to reach 163 zettabytes by 2025 and hence the need for simulation and modeling theory and practice. Simulation and modeling tools and techniques are of most importance in this day and age. While simulation carries the needed work, tools of visualizing the results help in decision-making process. Simulation ranges of simple queue to molecular dynamics include seismic reliability analysis, structural integrity assessment, games, reliability engineering, and system safety. This book will introduce simulation and modeling to practitioners, researchers, and novice users to the world of imagination.

Simulation and modeling programs are not like any other computer program. Section 1 can look at the amount of research being conducted in the scientific community, and the facts are reflected in Section 2. Section 3 shows the distinguishing factors of simulation. Section 4 presents classical simulation approaches and their handling of the time elements which is one of the distinguishing factors of simulation. Section 5 sheds light on the reasons why we simulation. Section 6 explains furthermore the different uses of simulation especially in training. Section 7 discusses the answer of proof of correctness or validation and verification question that is the second distinguishing feature of simulation.

2. Simulation in research

Simulation is a very important topic in the research community. According to the IEEE digital library in the year 2014, scientific journals and magazines published 9478 scientific research papers. In the year 2015, 10,371 scientific research papers were published, while in the year 2016, 11,133 scientific papers were published in journals and magazines. According to the same source in the year 2017, 12,206 scientific research papers were published. Hence, in the 4 years (2014–2017), 43,188 scientific research papers were published. The number indicates how rich the simulation topic is with undiscovered topics and many unsolved problems. Hence, the simulation topic is worth investigating.

3. Distinguishing features of simulation

There are four distinguishing charecterics that differentiate simulation from any computer program: time use simulation is an indexing variable, simulation

objective is to achieve correctness, simulation is computational intensive, and there is no typical use of simulation [1]. As time is an indexing variable, the use of such variable can be discrete or continues. Such use of the time variable is reflected in the approaches and method of simulation.

The second feature is reflected in the discussion of validation and verification of the simulation program. The section lists ways of validation and verification. To achieve correctness is a major goal of any simulation program; furthermore, the proof of correctness is a challenge of simulation.

The third feature is also another challenge in simulation world. Simulation major feature is the time indexing variable, which is a challenge on its own. Another element that makes simulation computational intensive is animation. Animation in relation with time variable is very challenging to master in any simulation program.

The fourth feature is distinguishing of simulation; there is no typical use of simulation. Simulation is colored with its use. The uses of simulation range from transport systems to molecule interactions. Hence, simulation is colored from within its use.

4. Classical simulation approaches

Simulation and modeling is an approach used when everything fails. Simulation and modeling applications range from nuclear reactions to transport systems. Hence, there are two types of simulation approaches: discrete simulation approaches and continuous simulation approaches. Process interaction approach, event scheduling approach, activity scanning approach, stock and flow approach, and three-phase approach all belong to the first family. In process interaction approach, the computer program emulates the flow of an object through the system. Transaction flow approach is a simpler version of process interaction approach. Event scheduling approach advances time to the moment when something happens next. The third approach, activity scanning approach, is based on two phases: the first phase is the execution after a fixed amount of time, and the second phase is the execution after the satisfaction of some condition. The third approach is a three-phase approach; as the name is suggesting, it has three phases: A, B, and C. To better understand the simulation approaches, **Figure 1** reflects the flow charts of each of them.
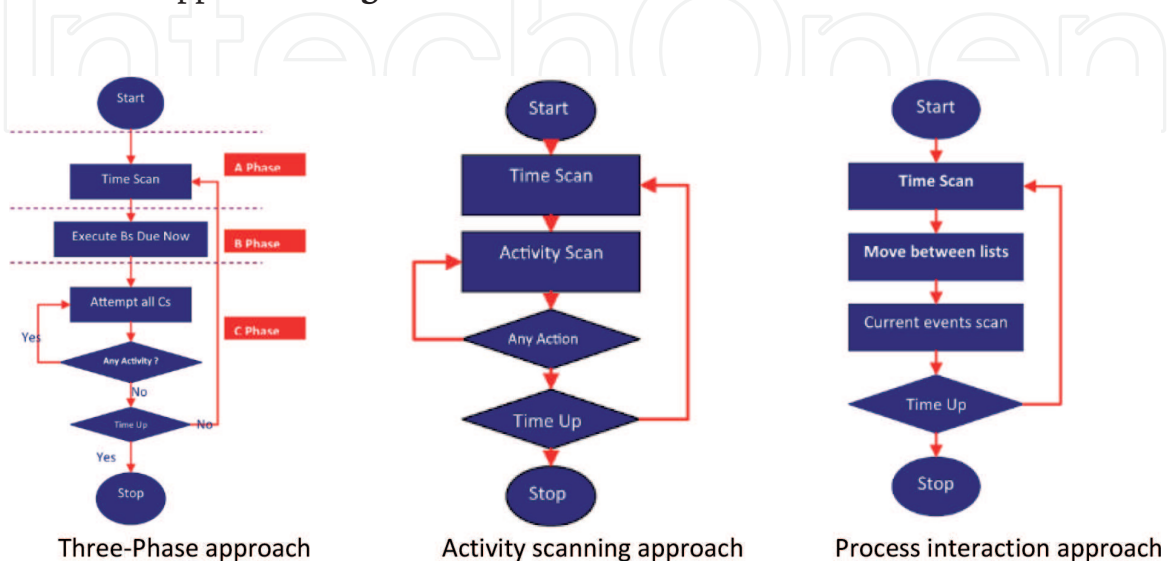

Figure 1.
Flow charts of the three classical simulation approaches [1].

To handle concurrent discrete event dynamic systems, Petri nets were developed by Carl Adam in the beginning of the 1960s, a theory for discrete parallel system. Such idea is reflected in the chapter "Petri Net Models Optimized for Simulation."

5. Why simulate?

Simulation and modeling needs imagination and innovations to be developed from scratch. Yet, simulation is needed and hence the question "why do we simulate?" Simulation allows experimentation rather than direct, costly, time-consuming experimentation. Simulation allows time control where the user can compress and expand time element. Simulation experiments can be replicated, so as to answer questions like "why did this happen?" Simulation allows the user to explore possibilities. Simulation allows the user to explore different possibilities while identifying constrains and predict obstacles. Playing with what-if scenarios, simulation is used to train pilots as well as medical professionals in the case of new technology.

6. Simulation uses in training

Simulation is used to train people in a number of arenas for many reasons: either the training situation is too dangerous to conduct or too delicate or too expensive. A study by Abu-Taieh and Abutayeh [2], they listed 12 areas where simulation is used for vocational training: to train pilots, many simulators are used. Rather than using the real plane to teach the pilot to fly, a simulator is used to train the pilot. Another use is to conduct chemical experiments by simulating the experiments. As such, the experimenter is in a safe environment while knowledge is transferred on handling chemical materials.

Another training arena is physics experiments. Simulators are used to conduct physics experiments. To teach things like motion, energy, power, sound, heat, electricity, magnets, circuits, light, and radiation, a simulator is used to teach their attributes and to visualize the experiments as seen in [3].

Mathematics, algebra, number theory, mathematical functions, trigonometry, data analysis, graphs, trees, networks, enumerative combinations, iteration, and recursion are hard topics to understand and visualize. Simulation is used as an explanatory tool and a visualizing method. Nelson [4] listed five reasons to use simulation in mathematics.

Simulation is used to study environmental and ecological systems. Since such arena is overwhelmed with variables that no mathematical formula can solve, simulation is used to study, visualize, understand, and explain environmental phenomena.

To study, understand, and explain cosmology and astrophysics, many computer-based simulators are used. Simulation in this case enhances the understanding of cosmology and astrophysics by visualization. Simulators are also used to train medical students in surgery training. Such concept is used to train novice surgeons to gain expertise and self-confidence before conducting the real surgery.

Simulators are also used in civil engineering, interior design, and architectural engineering designs. Since real-life experimentation is lengthy and expensive, simulators in such arena save time, money, and effort by delivering virtual product which can be altered rather than delivering real-life product. In Marshall

et al. [5], healthcare delivery is discussed using simulation. Other uses of simulation are to design, understand, test, and visualize computers and communication networks as seen in [6, 7].

To learn financial planning and to model marketing simulation is used, namely, in Crystal Ball and Analytica, among others. Business modeling, risk analysis, cost/benefit analysis, and risk management are also taught using simulators. In military training, virtual reality (VR) and virtual augmented reality (VAR) are used. Simulators like mission rehearsal exercise (MRE).

A published research [8, 9] classified 56 simulation environment according to their 22 uses: air traffic control and space systems, supply chain management, business process reengineering and workflows, transportation systems, complex system design evaluation, aerospace, computer and communication networks, oil and gas, computer performance evaluation, construction, education and training, financial modeling, healthcare systems, parcels and parcel handling(queue), manufacturing systems, de-bottlenecking, military/combat systems, what-if scenarios, satellite and wireless communications systems, robotic and mechanical systems, service systems, and decision and risk analysis.

7. Validation, verification, and testing (VV&T) in simulation

This section is an answer to the second distinguishing feature of simulation. VV&T in simulation is the most important quest. There is no point in simulating the wrong model and no point in simulating the model incorrectly. Validation answers to the question "Are we building the right model?" Verification answers to the question "Are we building the product right?" These two questions have been raised back in 1995 when Balci [10] published a research paper listing 15 simulation VV&T principles, as follows:

1. *V&V must be conducted throughout the entire M&S life cycle.*

2. *The outcome of VV&A should not be considered as a binary variable where the model or simulation is absolutely correct or absolutely incorrect.*

3. *A simulation model is built with respect to the M&S objectives, and its credibility is judged with respect to those objectives.*

4. *V&V requires independence to prevent developer's bias.*

5. *VV&A is difficult and requires creativity and insight.*

6. *Credibility can be claimed only for the prescribed conditions for which the model or simulation is verified, validated, and accredited.*

7. *Complete simulation model testing is not possible.*

8. *VV&A must be planned and documented.*

9. *Type I, II, and III errors must be prevented.*

10. *Errors should be detected as early as possible in the M&S life cycle.*

11. *Multiple response problem must be recognized and resolved properly.*

12. *Successfully testing each submodel (module) does not imply overall model credibility.*

13. *Double validation problem must be recognized and resolved properly.*

14. *Simulation model validity does not guarantee the credibility and acceptability of simulation results.*

15. *A well-formulated problem is essential to the acceptability and accreditation of M&S results.*

In the same paper, Balci [10] divided the V&V techniques into two categories: V&V techniques for simulation models and V&V techniques for object-oriented simulation models. The V&V techniques for simulation models were further divided into four subcategories: informal, static, dynamic, and formal. V&V techniques for object-oriented simulation models were divided into three subcategories: conventional, adaptive, and specific. The informal subcategory included 8 V&V techniques, and the static subcategory included 19 techniques. The dynamic subcategory included 50 techniques. The formal subcategory included eight techniques. The adaptive subcategory included 15 techniques, while the specific subcategory included 31 techniques. In total, Balci listed more than 130 validation and verification techniques; as such, this only reflects the importance of validation and verification in simulation.

Some published work like [8, 9, 11, 12] discussed the validation and verification quest. The first two sources listed the different methods and tools for VV&T, and the third source developed a method from within the system development life cycle of simulation.

8. Conclusion

Playing the virtual world with time element is a joy and challenge. Hence, simulation to simulators is an open-ended question. This chapter showed the importance of simulation from academic and scientific point of view and then the distinguishing elements of simulation. Two distinguishing features stood out: time element and the correctness of the simulation program. Time element handling is reflected in Section 4. Correctness of the simulation program is discussed in Section 7. In the overall picture, simulation and modeling is like an addictive game that one can never get tired of.

Acknowledgements

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