# Simulation and Agent-Based Simulation at WOA: 25 of Years of Simulation-Related Contributions, and an Outlook of What Awaits Us

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**Abstract.** The expression *computer simulation* implies the definition and adoption of a computational model to improve the understanding of some system's behavior and/or to evaluate strategies for its operation, in explanatory or predictive schemes. Computer simulation is quite diffused, since in many situations practical and/or ethical reasons make it impossible to directly observe a system that we want to study or manage. In these cases, the possibility of performing 'in-machina' experiments is often the only, hazardous way to study, analyze and evaluate models of those realities. The Workshop on Objects and Agents (WOA) venue is no exception: in several cases papers presented at WOA discussed simulations carried out to demonstrate the working of an agent-based model or software system, to calibrate or evaluate it. On the other hand, agent-based approaches also represented a set of conceptual, modeling and computational tools that are particularly suited to represent situations characterized by the presence of autonomous entities whose local behaviors (actions and interactions) determine the evolution of the overall system, often in non-trivial ways: agent-based approaches are, in other words, particularly in tune with some of the characteristics of complex systems. This chapter provides a bird's eye view of the relevant contributions presented at WOA in the last 25 years, highlighting the scientific impact of agent-based approaches in the more general area of simulation, and giving a perspective on what we can expect to witness in the near future for this area.

**Keywords:** Simulation · agent-based modeling · agent-based simulation

## 1 Introduction

"Computer simulation" belongs to a set of expressions used by a wide range of persons, belonging to very different groups, that are often employed without considering that the communication partners might not share the adopted conception and (typically informal) definition: it is a rather large set, and it also


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includes terms such as "model" and "system" that are even more present in everyday discussions without being rooted on proper definitions. Although we do not have the ambition of joining the philosophical debate on definitions of simulation (or simulation models [51]), we feel the urge to provide a working definition before we start exploring the set of relevant contributions presented at WOA in the last 25 years. To do this, we will borrow elements from the literature and from our prior works (mainly [15] and [12]), clarifying some fuzzy points thanks to the occasion of being invited to contribute this chapter, and trying to consider the evolution of the field.

Let us therefore define the term **computer simulation** as the usage of a computational model to gain additional insights into some system's behavior by envisioning the implications of the modeling choices, but also to evaluate designs and plans without actually bringing them into existence in the real world (e.g. architectural designs, road networks and traffic lights). For sake of simplicity, let us assume that a model is a representation of a system that is object of study (i.e. **target system**), and that the adjective computational adds sufficient precision, formality, and in general constraints enabling the model to be coded in an executable software system. In turn, we will consider a system as "a part of the world that a person (or group of persons) chooses to regard as a whole consisting of components, each component characterized by properties that are selected as being relevant and by actions related to these properties and those of other components" [108].[1]

The usage of simulators, that are thus a sort of "synthetic environments" reproducing essential features and mechanisms that are relevant to the goals of the analyst, is often necessary because the simulated system cannot actually be observed ever in principle (since it does not exist yet, it is currently being designed), or also for ethical (e.g. the safety of humans would be involved) or practical reasons (e.g. costs of experiments or data acquisition, observation of systems characterized by a very slow evolution). As a consequence, simulation can fit both very scientific and extremely practical, application-oriented workflows, kept together by the need of a proxy of a reality (either existing or desired) to be manipulated to support analysis, study, even decision making.

In the vein of what was already proposed by [54] or [78], we can introduce a schema depicted in Fig. 1, that proposes additional concepts of the overall simulation life-cycle:

– we surely have a *synthesis* part of a simulation project, bringing the analyst to define and implement a model and a simulator representing the target system; this artifact can be configured and used to carry out a set of simulations generally in different situations that are relevant to the overall goals of the study, a *simulation campaign*, producing a (potentially very large) set of data describing the dynamics of the system in those conditions according to the defined model;

[1] It interesting and significant that Krysten Nygaard was one of the creators of a language called Simula 67.

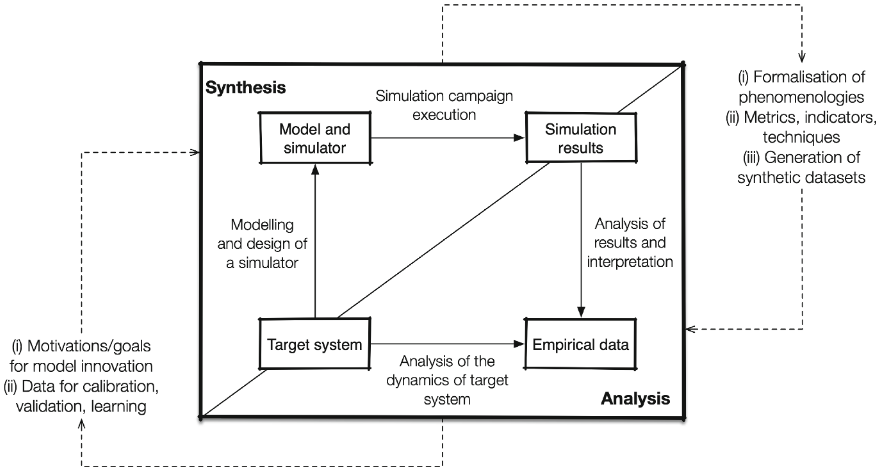



**Fig. 1.** Simulation as a predictive or explanatory instrument.

– there is necessarily an *analysis* part of the project, that is twofold: on the one hand, the raw data produced by the simulators need to be processed, analyzed, interpreted to produce insights. On the other hand, using a simulator in an "open loop" situation does not assure that the modeling phase led to the definition of a model and corresponding simulator producing results that are in tune with what would be observed in the simulated conditions. The loop must be closed, at least in a representative set of situations, by achieving data about the *actual target system dynamics*, that needs to be analysed to produce empirical data that can be compared with what is produced by the simulator.

For sake of simplicity, we can say that when the empirical evidences produced by simulation system are compatible with those observed in reality within a reasonably representative set of situations we can say that we have performed a *validation* of the model and simulator (the topic is of course more complicated than what we were able to say a few lines, more information can be found, for instance in [85]).

While simulation is typically more closely associated to the synthesis phase, the overall process calls for an integration among the phases, for activities of calibration and validation. Analogously, there are areas of research much more focused on the analysis of real world dynamics (e.g. time series analysis, pattern recognition in images and videos), but in some cases formalization of phenomena studies by means of simulation can provide useful information to research focusing on the analysis side (see, e.g., [139] where pedestrian group detection in videos considered mechanisms earlier adopted by pedestrian simulation models). Moreover, the exploitation of simulators for the production of synthetic datasets is a well-known, although always challenging, approach enabling machine learning (ML) based workflows for automated analysis [113].

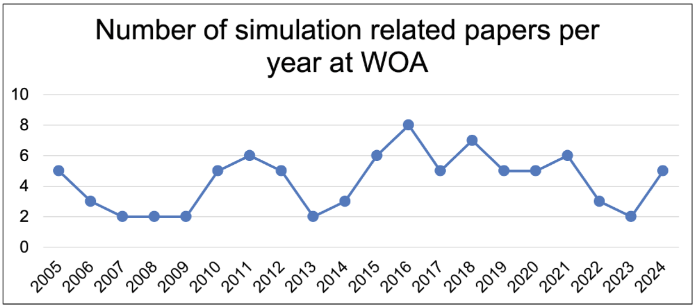



**Fig. 2.** Number of simulation related contributions per year at WOA.

## 2 Agents and Simulation: the WOA Perspective

Considering the above introduction of the scenario and especially the proposed definition of computer simulation, we considered the contributions presented at WOA and discussed at the workshop, trying to provide a bird's eye view of the types of work that have been produced by the community through time.

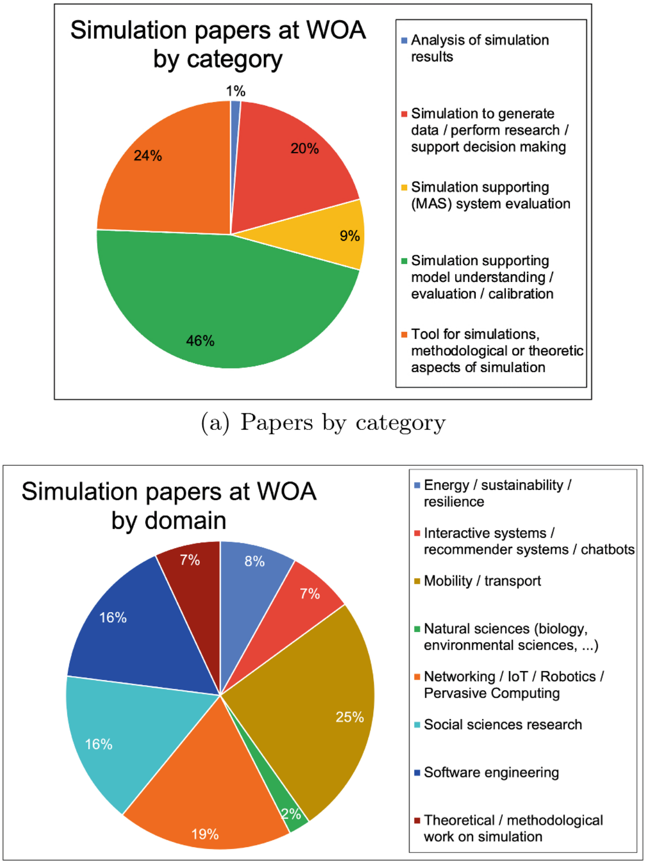
First of all, we started from two artifacts: (i) a large `bib` file including reference information about all papers presented at WOA since 2005, (ii) a spreadsheet including the above information plus abstracts. We selected relevant contributions for the present chapter by (i) filtering out papers not including any match to the pattern `simula*`, (ii) removing duplicates from the results (in some occasions WOA included a demo session in which poster papers could have the same title as the main workshop contribution), (iii) reading title and abstracts and evaluating if the contribution was actually relevant to the chapter.

Unfortunately, we were not able to process with analogous rigor proceedings from year 2000 to 2004: not all manuscripts were available to the authors, and having just the title was not sufficient to properly perform the following analyses[2]. Works such as [10,14,62] could be directly included in our analysis, but for many others simulation might be mentioned in the abstract as a way to evaluate a model or implemented system that is the central topic of the paper, and those works would have been impossible to consider and classify without having at least also the abstract.

As a consequence of the above process, we achieved 87 records of simulation related contributions.[3] The number of simulation related papers per year is

[2] This was not a light-hearted decision, but – on the contrary – we want to express our appreciation to excellent services that supported our work and the WOA community such as DBLP – https://dblp.uni-trier.de/ – and CEUR workshop proceedings – https://ceur-ws.org/ – and especially the AIxIA series, managed by Prof. Matteo Baldoni, that is also a pillar of the WOA community.

[3] In 2024 some contributions, denoted as "dissemination papers", were presented but not included in the proceedings, due to prior publication or since authors opted out of the publication process, for instance since the work was undergoing revision in another venue or was in press. These papers were not considered in our analysis, due to the fact that abstracts and manuscripts were not always available.




(a) Papers by category



(b) Papers by domain

**Fig. 3.** Breakdown of simulation related papers at WOA respectively by category (left) and domain (right).

depicted in Fig. 2; the most prolific authors of WOA papers in this subset are Giuseppe Vizzari (16), Giuseppe M. L. Sarnè (14), and Giancarlo Fortino (9), with a number of authors with 7 contributions.

We also defined two controlled vocabularies to add metadata to perform a few analyses of the achieved results, in addition to the obvious ones (such as the authors and the year of publication). In particular, we defined a *category* of contribution, meaning with this vague term the nature of the contribution, the main value of the paper. In particular, we defined the following categories:

– *simulation as main topic*: to support research in some specific domain, to support decision making activities about the target system, or to generate synthetic data: papers in this category are simulation systems that are rela-

tively close to practical applicability, they are on the border of technological transfer;
- *tools supporting simulation, methodological or theoretical aspects of simulation projects*: papers in this category deal with simulation as a central objective of the research, but they are of quite general value and applicability;
- *analysis of simulation results*: papers in this category are mostly focused on what happens after the simulation, and they deal with complex forms of analyses on data generated by simulations;
- *simulation supporting model understanding, evaluation, calibration*: papers in this category are not necessarily focused on simulation activities, but they essentially perform simulations to gain insights on the functioning of the models themselves, in controlled experiments, to support acquiring evidence of system dynamics in given conditions, or to perform evaluation, validation, or calibration activities; as such, these papers are not close to technological transfer, yet;
- *simulation supporting (MAS) system evaluation*: papers in this category are not about simulation, but they rather employ simulation as a form of evaluation of a software system, typically based on autonomous agents or a multi-agent system, or employing agent models or technologies for the simulation activity. Papers in this category are generally close to practical applicability and technological transfer.

The breakdown of papers in the above categories is shown in Fig. 3(a). As we can see, simulation is widely used to gain insights and empirical evidences on how an agent-based or multi-agent model works, or (moving closer to practical application) how a software system employing agent technologies performs in scenarios that mimic some real world deployment by means of a simulation scheme. This is particularly reasonable, since in many cases the agent-based and multi-agent paradigm is a natural choice for distributed systems (recently within cloud/edge/IoT areas), for which it is often hard to perform real-world experiments.

We therefore also defined a *domain of application* for the contribution, meaning with this vague term the areas in which the described model, approach, or software system is intended to be applied. In particular, we defined the following domains:

- *social science research*: synthetic agents have naturally been adopted as representatives of humans or aggregated forms of decision makers (e.g. households, companies) in forms of simulation trying to study socio-economical systems, in the vein of [78]; within the present volume, one chapter presents a discussion of *trust* [134], a very relevant and well studied aspect of social sciences through the lenses of computational modeling, with potential outcomes and applications also to interactive systems, discussed below;
- *natural sciences (biology, environmental sciences, etc.)*: agents have also been employed for the modeling of biological and natural systems, at difference scales and levels of analysis;

**Table 1.** WOA simulation related papers organized according to year of publication and category of research.

| | Analysis of simulation results | Simulation as main topic | Simulation supporting (MAS) system evaluation | Simulation supporting model understanding | Tools, methodological aspects | Total |
|---|---|---|---|---|---|---|
| 2005 | [13] | | | [68, 74, 126] | [11] | 5 |
| 2006 | | | | [33] | [60, 109] | 3 |
| 2007 | | | [72, 142] | | | 2 |
| 2008 | | | | [9, 66] | | 2 |
| 2009 | | | | | [76, 88] | 2 |
| 2010 | | [92, 105] | [79, 99] | | [89] | 5 |
| 2011 | | [16, 24, 90, 100] | [69] | [115] | | 6 |
| 2012 | | [32, 148] | | [73] | [91, 119] | 5 |
| 2013 | | | | [45] | [40] | 2 |
| 2014 | | | [128] | [71, 101] | | 3 |
| 2015 | | | | [43, 102] | [27, 39, 41, 120] | 6 |
| 2016 | | [104, 124, 130] | [70] | [46] | [30, 93, 125] | 8 |
| 2017 | | [18] | | [56, 103, 116] | [44] | 5 |
| 2018 | | [42] | | [21, 57, 131, 136] | [53, 63] | 7 |
| 2019 | | | | [64, 96, 122, 135, 143] | | 5 |
| 2020 | | [107] | | [87, 97, 121] | [80] | 5 |
| 2021 | | [114] | | [1, 23, 31, 58, 65] | | 6 |
| 2022 | | [86] | | [59, 127] | | 3 |
| 2023 | | | | [5, 144] | | 2 |
| 2024 | | [38] | | [112, 118, 123, 137] | | 5 |
| Total | 1 | 17 | 7 | 42 | 20 | 87 |

– *interactive systems, recommender systems, chatbots*: when developing interactive systems the notion of agent has turned out to be very useful, both to simulate actual users (something particularly in tune with the fact that these systems often defined and exploit some form of user model), and sometimes to design the interactive system as an agent, not necessarily but in some cases even with an embodied form; within this application domain, it is worth reminding that, within this volume, a chapter discusses models, approaches, challenges, and results on the topic of identifying (and potentially recommending) partners for interaction [129];
– *software engineering*: a long lasting line of research has seen the crossing of agent technology research and software engineering; simulation has played a role in many of these cases, mostly because the proposed system (designed or evaluated by means of software engineering principles and approaches) was a simulator or to support the evaluation or understanding of a proposed model;
– *networking, IoT, robotics, pervasive computing*: analogously as for the software engineering domain, agents are a natural approach for physically distributed systems, and simulation has been often employed to support the evaluation or understanding of a proposed model or a more mature software system, and sometimes specific simulators have been proposed to model and study very specific robotics systems (i.e. drones); with reference to this domain of application, we remind that a chapter in this volume discusses specifically how software agents can represent a viable solution for intelligent IoT systems [25], while another chapter discusses the Aggregate Computing approach [25] to the programming of collective adaptive systems;
– *mobility, transport*: the traffic and transportation application domain is a particular kind of socio-technical system that, due to the intrinsically distributed nature of the studied phenomena, has often witnessed the application of agent-based models [19];
– *energy, sustainability, resilience*: recent attention to sustainability issues and resilience (we included simulations and researches focusing on measures limiting epidemic outbreaks in this domain) has also influenced the contributions discussed at WOA;
– *theoretical or methodological works on simulation*: finally, also from the point of view of this controlled vocabulary there are works of very general nature, whose applicability spans across the above domains.

The breakdown of papers focusing on the above domains of application is shown in Fig. 3(b): on the one hand, this distribution reflects the research interests of members of the WOA community. On the other hand, it is surely influenced by exogenous tendencies (that have manifested themselves in a dramatic way during the COVID-19 outbreak) and that however see a growing push to achieve *societal impact*, that has become one of the established factors for the evaluation of scientific research, and it is basically the common element shared by the *Sustainable Development Goals* defined by the United Nations[4].

[4] https://sdgs.un.org/.

The results of the presented analysis are also shown in a compact way in Table 1 that lists simulation related papers organized according to year of publication and category of research.

## 3 Agents in Simulation Research

The above analysis of simulation related papers at WOA confirms that, besides supporting research in computer science and engineering already working with agents, research on agent related concepts, models, and technologies has also been instrumental to support scientific research in an impressive range of additional disciplines. A non exhaustive list of areas, that can be useful to have a glimpse of the pervasiveness of the approach, would include social sciences in general [78], in particular an approach called Agent-Based Computational Economics [140], biology [117], urban planning (and sustainability) [106], energy systems (and markets) of different kinds [52], traffic and transportation [19] (in particular we want to highlight the Agents in Traffic and Transportation, a long lasting workshop series that has orbited around the main international conferences in Agent technologies and AI in general for over 20 years[5]).

Various approaches developed in the different areas show, of course, significant differences from a formal, technical, and sometimes also epistemic point of view, but the common standpoint of all the above mentioned researches (and of many other ones that legitimately describe themselves as agent-based) is the fact that the analytical unit of the system is represented by the individual agent, acting and interacting with other entities in a shared environment. This represents a significant difference from models in which the observables are typically the *quantities* of agents, and what is being modeled is their variation over time. For instance, the venerable Lotka-Volterra population dynamics model [149], defined to model the complex interaction among two species, one of which feeds upon the other, is essentially defined as:

$$\frac{dx}{dt} = \alpha x - \beta xy,$$
$$\frac{dy}{dt} = -\gamma y + \delta xy,$$

where $x$ is the number of preys, $y$ is the number of predators, $\alpha$ and $\gamma$ (constants) account for the efficacy of respectively the prey and predator reproduction processes, $\beta$ (constant) defines the link between the prey mortality and the number of preys and predators, and $\delta$ defines the link between the increase in predators to the number of prey and predators. Despite the age of this model, the overall approach has shown its adequacy to represent nonlinear dynamics and support reasoning and scenario building in the recent COVID outbreak (through Susceptible, Infected, Removed – SIR – or Susceptible, Exposed, Infected, Removed – SEIR – models [82]), and using proper model extensions to account for spatial

[5] http://www.ia.urjc.es/ATT/.

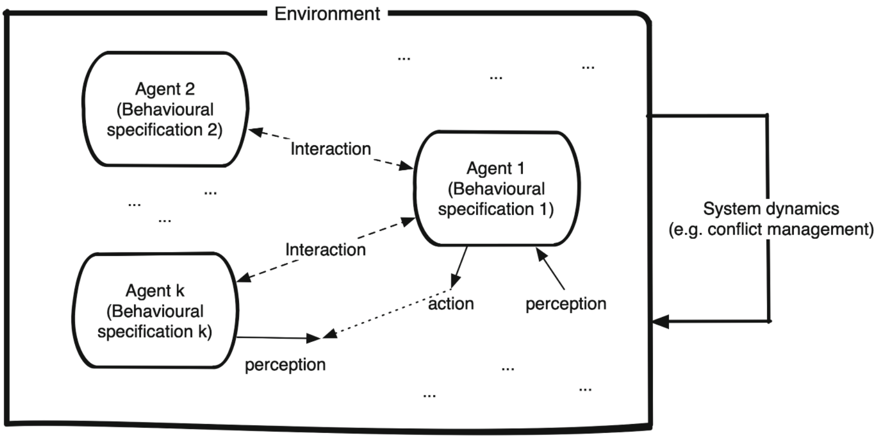



**Fig. 4.** A reference model for agent-based approaches to simulation.

aspects researchers were able to evaluate the impact of containment measures in terms of reduction of casualties, by exploring counterfactual scenarios [77].

Agent-based models, on the other hand, do not prescript an overall global trend of observables, whereas the overall system dynamic is rather the result of individuals' actions and interactions within the environment. Agents, within this approach, are not governed by outside global rules, but they rather perceive, choose the action to be carried out, by decision making mechanisms that can range from simple reaction rules to knowledge–level processes. It must be stressed that, in some areas of application, agents can represent entities that do act in an environment, but these actions are basically due to the application of physical laws, rather than autonomous decisions. When agents do take decisions, and especially when they represent humans, again research on the synthesis side of the research calls, and in generally interacts with, research on the analysis side, as discussed in the introduction. Whatever the action selection process, the agent attempts to carry it out in the environment, as schematized in Fig. 4. Agent naturally interact indirectly simply because they (and their actions, and the effects of their actions) can be perceived by other agents, but also direct interaction mechanisms could be employed when necessary, convenient, or simply plausible according to the specific modeled reality.

Agents and interaction are therefore central concepts in this kind of models, analogously as in any other scenario of application of agent technologies, but agents' environment [150] within simulation project plays (if possible) an even more prominent role, since:

- it deeply influences the behaviors of the simulated entities, in terms of perceptions;
- it manages dynamic process that unfold independently of agents [83], and it performs an overall regulation function on the overall system [17];

– the aim of the simulation is to observe microscopic or aggregate level behaviors (e.g. the density of a certain type of agent in an area of the environment, the average length of a given path for movements, the generation of clusters of agents), that can actually only be observed in the environment.

Compared to the macroscopic approach taken by population dynamics models, agent-based models require additional information, knowledge, insights about the structure and functioning of a system: getting back to predators and preys, we need to know substantial additional information about these organisms; we cannot simply observe real world situations and fit the constants in order to achieve a plausible overall dynamics. On the other hand, if we are able to somehow express this additional knowledge, we can perform analyses that would have been otherwise impossible, due to the fact that the concepts of interest would have been hidden in constants within equations. For instance, a particular kind of environmental structure and vegetation might make it easier for predators to catch their preys: this can be explicitly considered in an agent-based model, whereas it would be represented as changes in the values of constants $\beta$ and $\delta$ in a Lotka-Volterra model. Agent-based modeling has also been suggested as a potentially useful tool within "learning-by-modeling" approaches that can improve our knowledge of complex phenomena [141]: basically, by requiring the modeler to specify additional knowledge about the simulated system and, in parallel, by calling for more granular experimentation, evaluation, and finally validation of the proposed model, this approach represents a potentially useful workflow to support rigorous scientific investigation leading to further discoveries.

While we discussed in pretty abstract terms the role and the specifics of agent-based models in simulation, other chapters of the present book suggest concrete ways to put together specific agent-based approaches and specific domains of application [75], by describing meta–models of agent-based systems [37] and showing how they can be applied to cases of study.

## 4 Concluding Remarks and a Glimpse at the Future

This chapter has discussed how simulation was an important topic within the set of researches carried out, and discussed at the WOA workshop. First of all we proposed a definition of the term simulation, and a basic workflow of simulation projects. We then analyzed the contribution of relevant research related to simulation carried out at WOA. Not all of these researches have taken an agent-based approach to simulation, and quite often simulation represented a way to support the understanding and evaluation of the workings of some agent-based system whose goal was not simulation. We finally therefore took a closer look at the specific nature of agent-based approaches to the definition of a simulation model, comparing the approach to macroscopic modeling approaches, and proposing a reference model that can help comparing the inevitably extremely heterogeneous approaches that have been defined in extremely different disciplines and areas of research.

Although we paid particular attention to the research that was discussed at WOA, we want to stress that this local observatory mainly reflected, elaborated, and presented an original perspective on the progress of scientific research that extends its reach far beyond the Italian community.

We want to emphasize three messages that are rooted in what has been discussed in the chapter, but that we want to further elaborate here.

First of all, **agent-based models are inherently more expressive** than alternative approaches to the modeling and simulation: although agents in simulation are often simpler than those employed for the design and implementation of distributed systems, agents can be heterogeneous, they require precise and potentially complicated perceptive capabilities, behavioral specifications, mechanisms of interaction among themselves and with the environment. An agent-based model is richer, more "colorful" than most alternatives. However, **"with great powers comes great responsibility"**:[6] the risk, for the modeler, is to create extremely rich and extremely ambitious instruments, characterized by the usage of numerous parameters, including a high number of internal mechanisms leading to diverse pathways of overall system evolution. However, simulation models are tools that support rigorous forms of investigation and need to face systematic forms of evaluation and validation. The agent community has created powerful conceptual and computational tools supporting the design of intelligent distributed systems, but simulation is a quite peculiar task and one should be careful in adding elements that can hinder the possibility to perform sensitivity analyses [145], validation of the developed models and simulators, and more generally to faithfully replicate observed patterns or analyze achieved results to understand reasons for some observed effect.

Second, and sometimes related to the above point, scientific researches on complex systems have been carried out for a very long time **without agent-based models**, even without computational tools at all. While in some areas microscopic, agent-based simulation is completely accepted and used on an everyday basis supporting decision makers and designers,[7] for COVID-19 scenarios the most credible studies were carried out employing spatial extensions of SEIR based analytical models, such as the already mentioned [77]. This can certainly reflect the different level of maturity in models and tools developed in different areas, but it often reflects a deeper problem with *credibility* of a model and related simulators [111]. The role of research is, however, not quite the same as the one of professional software developers or software houses, and controversies related to the present scenario, and in particular the fact that sometimes frontier research is carried out using and sometimes producing software, were

[6] The proverb has been popularized by Spider-Man, but it has been used even by the Supreme Court of the United States of America (https://en.wikipedia.org/wiki/With_great_power_comes_great_responsibility), so why shouldn't we?.

[7] For instance, for pedestrian and crowd simulation, despite research is still very active, commercial tools such as PTV-Viswalk (https://www.ptvgroup.com/en-us/products/pedestrian-simulation-software-ptv-viswalk) are widely used and well reputed; analogous considerations can be done for multimodal traffic simulation (see, e.g., PTV-Vissim – https://www.ptvgroup.com/en-us/products/ptv-vissim).

already discussed in [98]: the quality of research prototypes and scientific software is often questionable, to the point of casting shade and doubts on the results achieved through their usage. We can surely say that the problem, if possible, has grown since then. Will the open science movement bring some direly needed improvements? Only time will tell, but we want to stress that even in the agents community releasing code as open source is still not that frequent [26].

The third point we want to discuss more deeply is related to the **growing adoption of ML approaches for simulation**. Gartner's Innovation Insights more broadly talks about "AI Simulation"[8] saying that the topic is about "AI and simulation increasingly work together to enable more versatile and adaptive systems". Some of the works discussed recently at the WOA workshop, and in external venues (see, e.g., [146]), do represent attempts to investigate the possibility to achieve a simulation model, more specifically an agent model to be used within a larger model for the simulation of some complex system, by means of some machine learning technique (Reinforcement Learning – RL – in particular seems a quite straightforward approach, due to the inherent presence of a learning agent in a RL setting). On the other hand, the Sim2Real [84] line of research represents an attempt to combine learning and simulation by proposing to transfer predictive models and control programs trained through simulations directly to the real world. We mainly talk about the line of work that employs ML for simulation, and we can say for sure that these attempts will increase in number and quality: it is actually already happening, also in research areas outside computer science and engineering, further increasing the fragmentation of research on or around ML. We have two warnings to researchers spending time and energies in this direction: first of all, we need to consider that **the success criterion for a simulation project is not optimality of the efficiency of the simulated system**, or some agents within the system, but rather **the capacity to plausibly reproduce some phenomena observed in the real world** [147]. Moreover, and connecting this point to the first one, let us remember that **the journey we follow within a simulation project is often a quest for the improvement of our knowledge** on a specific object of investigation, and - again - agent-based approaches can be more difficult to adopt because they might require more knowledge than what the state-of-the-art makes available. The above mentioned work describing a "learning-by-modeling" approach [141] is again very appropriate and worth mentioning again. Non ML based approaches are demanding, they often call for interdisciplinary works, sometimes with slow advancement and results of limited applicability, works with lots of *caveats*. Simulation projects are hard, people talk about "art and science" [138] for simulation, and sometimes even "dark arts" [94], but it has represented and it still represents a sound approach for conducting scientific research and increase our knowledge. ML represents a completely legitimate instrument to solve problems, and even a very practical tool not just to be employed somewhere around simulation projects, but as **a substitute of a whole simulation model**. We are, however, **not so sure that ML will be**

[8] https://www.gartner.com/en/documents/4037399.

**as useful as manually defined models to acquire new knowledge** about the object of investigation of the simulation project, due to the fact that ML models are much less transparent and interpretable.

Simulation for agent research, as well as agents within simulation research, are however both here to stay. Every new technology needs to be studied in synthetic environments to evaluate it, its effectiveness, efficiency, potentially unintended implications before being deployed in the real world. Agent technologies are no exception to this need. Microscopic level analyses of complex systems, considering the fact that overall dynamics depend on local decisions and actions taken by (to a certain extent) autonomous but interacting entities, are simply necessary to face the challenges raised by the need to regulate (or at least influence) these systems, and steer them away from global undesired destinations. Simulation models might not be able to grasp all the complexity of scenarios like global warming, global pandemics, geopolitical crises, but they do represent a useful tool to study them and possibly advance our knowledge. The interplay and synergy among research on the synthesis of agents' behaviors, potentially also by means of ML approaches, and analysis of complex systems is even more urgent and central within this kind of developments: research fragmentation, disciplinary barriers, reproducibility crisis [3], as well as the huge inflation of the number of published research papers [81] represent threats to a virtuous growth of this research area, as well as to the overall scientific research process. The whole research community should be thinking about these issues: maybe we should contribute to this discussion. Why not considering employing agent-based simulation for performing what-if scenarios? Well, let's talk about it in 25 years, at WOA 2049!

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