Using games to design rules for agent-based models: a research agenda

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***Abstract*—Agent-based modelling is a popular and suitable tool for analysing complex socio-technical systems. In order to come to valid simulations, it is important that the source code of agents is of sufficient quality. For agents that represent actors, this implies that they must show sufficiently realistic behaviour. However, formalizing human behaviour into mathematical symbols is a challenging task, because of, among other things, the gap between analytical (context-independent) knowledge about behaviour, and actual context-dependent behaviour. It has been suggested that gaming simulations can be used to support the modelling process of agent-based models. However, such an application has not been further developed. This article aims to make the first of many steps on the way to developing a feasible and usable new method to support the design of rules for agent-based models, namely by using games as a data collection tool. A theoretical scientific foundation is provided for the proposed method and there will be elaborated on the specific assumptions that are made. Finally, a research agenda is provided, which can be used as a guideline for further research in order to develop this application of games.**

I. Introduction

Agent-based modelling (ABM) is a popular simulation modelling technique centred around the concept of agents and their interactions [1]. It is applied in many different fields of research [2], [3], among others to analyse so-called 'socio-technical systems' [4], [5]. These systems consist of both technical artefacts (the physical infrastructure, e.g. pipelines), and many social artefacts (relevant actors and institutions, e.g. end users and governments), which are intertwined with each other and strongly interact [6]. The interconnectedness between multiple artefacts, both within the technical and social networks, as well as between them, leads to a high complexity [7]. Examples of socio-technical systems include power grids, transport networks, and residual heat networks. When ABM is used to gain insight in socio-technical systems, the central experiment is to situate an initial population of autonomous heterogeneous agents, allow them to interact according to simple local rules, and thereby generate the macroscopic regularity, conform [8]. Thereby, there is no desired state or task that needs to be achieved, it is only an exploration of the system's possible states [4].

Within the paradigm of ABM, an agent can be defined as a "persistent thing that has some state we find worth representing, and which interacts with other agents, mutually modifying each other's states" [9]. Furthermore, in his definition Jennings [10] mentions the capacity of an agent to be flexible and autonomous in order to meet its objectives. When socio-technical systems are simulated in ABMs, it is important that agents represent, among other things, the relevant actors, e.g. companies, or individuals. Because rules of agents on micro-level, affect the direct behaviour of agents, and may also have significant consequences for the emergent behaviour on macro-level [11], [12], rules of the agents must be of sufficient quality, in order to generate valid modelling results. For agents that represent actors, this implies that they must simulate sufficiently realistic behaviour.

However, capturing human behaviour with mathematical symbols is a challenging task. Autonomous agents with local rules allow us to take social aspects into account to a certain level. However, given the richness of human behaviour, i.e. the large diversity of (possibly subconscious) variables, actions and goals, a digital model will, per definition, lead to a simulation in which social rationality is under-represented [13], [14].

An other aspect that affects the realism of agent's behaviour concerns the formalization from (general) knowledge about the system, to source code for agents. Currently, the design of (the behaviour of) social entities in ABM, is to a large extent based on literature studies [4]. The majority of literature within the social and behavioural science is analytical in nature. Within analytical science, the major scheme is to develop a theory and test or justify it using variables and correlations. Thereby, there is a tendency to rule out as many context variables as possible in order to reach statistical significance [15]. This results in general, context-independent conclusions or 'social laws' (as far as we can speak of laws, since they are not always applicable, but based on statistics). On the other hand, within design oriented science, which includes ABM, context is very important. Products and models are designed and evaluated in a specific context of use [15]. One can feel intuitively that behaviour is very context-specific. It is very well possible to identify general patterns of human behaviour from literature. However, we are interested in general patterns of behaviour *within* a specific context. Generally, studies within social and behavioural science do not provide us with concrete answers to this.

It has been suggested that gaming simulations can be used to support the modelling process of ABMs: "The idea is to use real life players that play a serious game as 'programmers' of

ABM. [...] Ideally, in combining the power of both we will be able to develop a model of a human player, and then examine its response over a wide parameter space" [1, p. 250]. Such an application of gaming sounds promising, but has not been further developed. The objective of this article is to make the first of many steps on the way to developing a feasible and usable new method to support the design of rules for agent-based models. Thereby the focus lies on the simulation of realistic behaviour.

The next section will elaborate on gaming and the foundation to use games to support the design of rules for agent-based models. At the end of this Section a specific application is proposed, namely using games as a data collection tool for agent-based models. This application, and its main assumptions, is explained in Section 3. In Section 4, a research agenda is given, which can be used as a guideline to further develop this application. In Section 5, the conclusions of this article are provided.

II. Gaming

A. Gaming as tool

Gaming can be considered as using a game to simulate (a part of) a real-world system. A game can be defined as a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome [16]. Gaming can be seen as an alternative approach to computer simulations. The elements of a system can be simulated in various ways, e.g. with cards, a board, or a virtual environment. The social part of a system can also be represented by the players of a game. Instead of modelling humans with mathematical symbols, they are integrated into the simulation by giving them a role. Players can either be random participants, but also be the actual stakeholders of the real-world system [17]. "As participants take values and beliefs from their real life with them into a game, e.g. culture, it can be made part of a model without the need to formalise it in a (computer)model" [18, p. 26]. This makes gaming suitable method for modelling the social artefacts of a system. Based on work of Gibbs [19], Meijer [18] subdivides the structure of a game into four elements: roles, objectives, rules, and constraints.

1) Roles: The role in a gaming simulation refers to the position or function of the player or game leader. These roles can match with the roles from the reference system, e.g. the role of Port of Rotterdam Authority in the game *SimPort-MV2* [20], but do not necessarily have to, e.g. the role commander of an army in *Chess* or the role of mayor in *Sim City 4* [21]. Different roles may have different objectives, may be capable of different actions, or may be a combination of both aspects. Information about the role can be presented very detailed, as part of the preparation, but also very concise, which requires the player to research his part [19].

2) Objectives: The objectives, or goals, are the desired results where a player strives for. Objectives can be expressed in aspects of the game, such as a minimum amount of points, or the fulfilment of a specific task. "The gaming element in a gaming simulation means that participants will be motivated to win or do the best they can in a session" [18, p. 25].

3) Rules: The rules of the game define how the game is played and how game-play emerges, by determining what is allowed and what is forbidden. As with roles, rules can match with rules from the reference system, but not necessarily need to. Furthermore, these they may apply to one specific role, or to all players. Rules may be subject to variation, but too much change, or the variation of certain characteristic rules, may result in a new games.

4) Constraints: Constraints limit the range of actions possible in a gaming simulation. They differ from rules as constraints limit the (in-game) world, while rules shape (inter) human behaviour.

B. Experimenting with games

There are many applications for which games are used [22]. In this article we focus on games that are used for research purposes. One of these applications is performing scientific experiments with games as research tool. Certain research questions are impossible to investigate directly, e.g. because the system is inaccessible for outsiders or because the system does not exist yet, since it is an exploration of the future. A game simulation, is one of many methods that can be used to simulate such systems, and investigate the research questions [22].

However, the use of games in an experimental context is not limited to the simulation of inaccessible systems. Games are frequently used in both experimental, and behavioural economics [23]. The data collected in these games is used, for example, to design, improve or validate economic theories or to analyse strategic decision making behaviour [24]. Examples of categories of these types of games include market games, public good games and coordination games. The games used in this field of research are used in a way, comparable with structured lab-experiments. This results into the fact that most games are fairly small and abstract, in order to control the number of variables. Hofstede and Meijer [15] argue that it is also possible to use data from gaming simulations in quantitative empirical methods, when more context is present (and thus 'disturbing variables'). A requirement, then, is that there is sufficient data available to analyse. In this form, games can also be used to extract information or opinions from the players. "In this sense, the game becomes the rough equivalent of a questionnaire. However, it is much more powerful than a questionnaire in that it becomes an opportunity to observe the response of an individual in context as opposed to the artificiality of the response normally associated with questionnaires" [25, p. 78-79].

From the previous subsections we can derive some important observations:

Firstly, gaming allows us to take social complexity into account. Players are important elements in games. They constantly interact with each other and become part of the system. These players, who have been assigned different roles, can represent the important actors and stakeholders of a reference

system. Humans (and not agents) make decisions, and thus social complexity and social rationality will play a significant, far more realistic role, compared with computer models. This may result in more realistic states and outcomes with regard to the social aspect.

Secondly, it is possible to perform experiments in which games function as environment. The game designer has a large amount of control over the environment and the structuredneess of the game [18]. Within this environment players can behave freely. This makes gaming a good combination between the structuredness of experiments and the freedom of case studies, and allows us to capture the capricious behaviour of human beings in a semi-structured way. Furthermore, given the adjustability of roles, rules, objectives and constraints, it is possible simulate the reference system, or to implement the relevant context of the behaviour.

Thirdly, gaming simulations, unlike questionnaires, interviews and computer simulations, provide the possibility to examine actual behaviour [18]. Humans do not always correctly indicate how they behave, e.g. for strategic reasons, or because they do not know (precisely) what they do. Using direct observations as a source of information decreases this bias. Furthermore, gaming provides the opportunity to observe human behaviour, within (an abstraction of) the desired context.

From these aspects we can conclude that, when we assume that the game is a valid representation of the real world, and the players behave in a realistic manner, gaming provides an excellent possibility fill the gap between an analytic analysis of and applied model-design, as it functions as a context specific experiment. A game, then, is used as a tool to generate and extract relevant behaviour from humans during game play. This data can be used to draw up rules for agents in agent-based models.

III. Gaming as a data collection tool for agent-based modelling

In order to design a valid and feasible tool to design rules for agent-based models, it is important to elaborate on the exact assumptions of the new method. The starting point of the method is our view on the real world. We maintain a socio-technical systems perspective, in which multiple technical and social artefacts exist and interact with each other. As mentioned earlier, the focus will lay on the social artefacts. The actors of the reference system all have (personal) characteristics, such as personality traits, and the availability of certain resources (money, skills etc.). Furthermore, all actors have one or more interests which they try to pursue. Their behaviour towards these goals is shaped by different kind of institutions. These can be defined as "the set of rules actually used by a set of individuals to organise repetitive activities that produce outcomes affecting those individuals and potentially affecting others" [26].

The four layer model of Williamson [27] offers an institutional framework, in which four different levels of institutions are identified. The first level is the social embeddedness level and includes the informal institutions, such as norms, customs, and values. These influence the mindset of actors. The second level is the institutional environment and includes the formal, political and legal rules of the game. The third level is called the governance level. Here, those institutional arrangements are located that coordinate specific interactions between individuals. The fourth level, is the level of the individual actors and their interactions. These four levels influence each other and are tied to different time scales. The model also has been used to develop a dynamic layer model of socio-technical systems [28], [29]. Is not within the scope of this thesis, to go further into detail on these topics. For an elaboration see, e.g. [27], [29], [30]. For now, the identification of different institutional levels is sufficient and useful for clarifying some assumptions and mechanisms of our method.

The behaviour of the actors in the real world, is shaped by institutions from all four layers. All actors have a certain mindset that is influenced by personal characteristics and by informal institutions, such as norms and culture. With this mindset actors form, together with technical artefacts, the real world system. The behaviour within this system is constrained by all kinds of formal rules, such as laws. Within this confined system, individual actors make decisions trying to pursue their interests, thereby interacting with other actors and making all kinds of decisions. It is possible that these actors make institutional arrangements, such as contracts or verbal agreements, in order to do this.

In a gaming simulation, the real world is represented by a game environment. Players are assigned to roles with one or more goals, to represent the actors and their interests. The mindset of players is influenced by their personal characteristics and by the informal institutions from the world they live in. Therefore, it is important that these do not differ too much from the roles they have to fulfil, in order to come to valid representation of the system. The relevant formal rules of the real world are represented by rules and constraints of the game. These can be designed and/or shaped by the modeller. The main assumption is, that when these first and second layer institutions, together with roles, goals and resources, are validly represented, the third and the fourth layer institutions will follow in-game. In other words, when the behavioural space of the game is similar to that of the reference system, we expect that players will behave, and make similar agreements with other players as they would do in the real world. This implies that the behavioural patterns within, and the outcome of the system should be similar to those in the real world.

The next step is to analyse these behavioural patterns. This includes investigating the end-states of the system, but also to the paths of individual decisions and actions that lead to these states. There are multiple methods to 'capture' these patterns, e.g. information trails, questionnaires, direct observation and interviews. Which method is used, depends on the specific situation and type of variable.

Based on this analysis rules for an agent-based model can be drafted. Because an agent-based model is a fully digital method, all relevant institutional levels must be modelled by

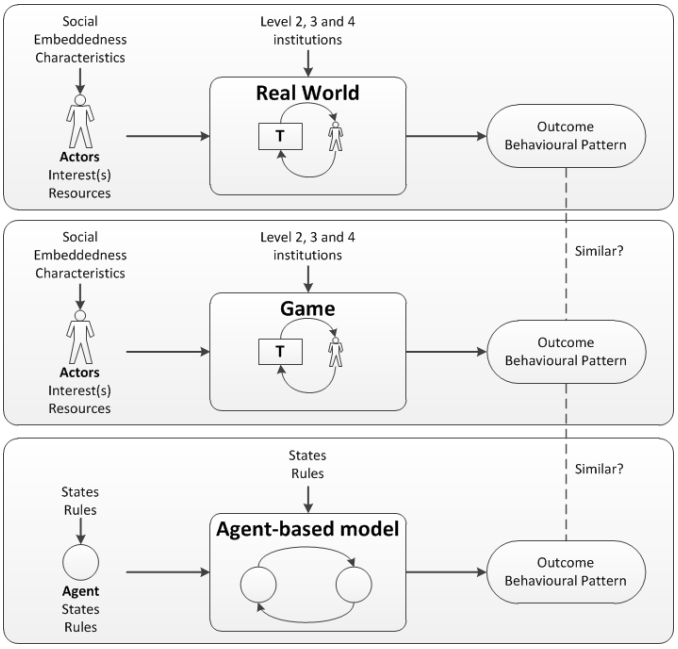

Fig. 1. Schematic overview of the aspects that shape behaviour in the real world, in gaming and in agent-based modelling

means of states and rules. The goal is, then, to make the agents behave like the actors in the real world (and thus the players in the gaming simulation). An schematic overview of the aspects that shape behaviour in the real world in comparison with the gaming and agent-based modelling can be found in Figure 1.

IV. A RESEARCH AGENDA

In the sections described above a theoretical foundation has been provided for using a game as a tool to support the design of rules of agent-based models. Before this application can be considered as a useful support-tool to develop, many important questions need to be answered. In this section, we identify some lines of research that are required to come to this goal.

A. Practical applicability

The most important requirement of a support-tool is its practical feasibility. As we have seen, games can, in theory, be used to support the design of rules for agents. However, no actual implementation of the tool has been realised so far. Therefore, the first line of research should go out to showing the practical applicability of the tool. A proof of principle should be developed to show this. Also, this research can reveal practical difficulties and give a better indication of its feasibility.

Because games have been used as a method to perform experiments with, it is very likely that this proof of principle will show that the method is applicable in practice. It is, therefore, more interesting to see to what extent the tool is applicable. A wide range of dimension, all with different characteristics must be tested to provide more insight in whether, and how, the method is applicable. This can be tested on different dimensions:

- different types of games (e.g. different mediums, various time ranges, number of players)
- different types of system representations (e.g. a partial or holistic representation of the reference system, the use of metaphors, using the actual stakeholders or not)
- different types of behaviour (e.g. reasoned behaviour, habitual behaviour, normative behaviour).

It is reasonable to assume that different characteristics require a (somewhat) different design approach, or that certain combinations are required, or not possible. An extensive framework should be designed in which these aspects are clarified, and which can be used as a guideline during the design process of the game.

It is also interesting to see whether a differentiation can be made from the perspective of agent-based models. Recall that the proposed method is within the context of analysing socio-technical systems, i.e. exploring the system's possible states. However, even within this specific context it is possible to distinguish between the goals of a method, e.g. models to explore the effects of specific policy measures, or the analysis of the robustness of a system. Different goals may require a different quality of data, leading to different design choices.

B. Usefulness of the tool

Another obvious, but nonetheless very important requirement of a support-tool, is that it must contribute to the design of rules for agent-based models. More specifically, we aim to collect valid data, in order to design rules to make agents behave more realistically. Thus, there should be demonstrated that the proposed tool actually improves the quality of rules. However, is not an easy task to show this improvement, because, among others, agent-based models make an exploration of future states of the reference system. These states, thus, do not exist yet, and cannot be compared with reality (cf. the difficulties with the validation of agent-based models). Therefore, follow-up research should be done in which an existing or historic system is simulated via two ways, with and without the support of a game. Then, the output from both methods can be compared with real world data. If the agent-based model that is designed with the help of a game, as expected, appears to produce the most realistic data, this will give us some confidence that it will also do so in future systems.

Demonstrating the usefulness of a method, however, takes more than examining the objective improvement compared to other methods. A new method tool should be sufficiently useful, i.e. the benefits should outweigh the costs. Concretely, this means that the improvement of the quality of the rules must be at least proportional to the development and operational time and costs. To analyse the relative usefulness of the support tool, these costs and benefits should be identified.

These costs strongly depend on the size and complexity of the game. However, it is clear that the data collection tool has the potential to become expensive and time consuming. On beforehand, decent estimates can be made of these costs, based on experience and other game design projects. However, there

must be remembered that the validation process for games with this specific application can take longer than for games with other purposes, since the focus lies on representing realistic behaviour.

The benefits of the method are much harder to determine. The reason for rules to be more realistic, is to reduce the disturbing effect on the rest of the model. In part this relates to the specific behaviour of the agents, but it relates far more to the system outcomes. We have argued that simple rules already may lead to very different system behaviour. However, this does not mean that every rule that leads to unrealistic behaviour causes the whole model to be invalid. If this is not the case, the necessity of retrieving realistic behaviour is far lower, decreasing the benefit of the proposed method. Given the bottom-up nature of agent-based modelling, the potential disturbing effect of one single rule on the system behaviour is very hard to predict, let alone the effect of multiple, interacting rules. We assume that the more connections, both input and output, an actor has got with the rest of the model, the more likely an agent's behaviour influences the model as a whole. However, further research should be done to this challenging topic, to examine, for example, whether there are certain types of rules or causal structures that might influence (and thus disturb) the model relatively more. Ideally, a tool will be developed in which the ABM-modeller can test this disturbing effect, and decides to put more attention to this rule, e.g. by using a game to design it.

Another aspect that affects the benefits of the tool, is the quality of the data that are produced. The focus of the tool lies on the generation of realistic behaviour by means of a game. However, a game is per definition a simplification of the reference system. Furthermore, due to the interdependent design elements, discussed in this thesis, design choices may be required, that negatively affect the generation of realistic behaviour. The main question, then, is what the quality of the generated behaviour is. This is a particularly difficult question since there is no objective measurement scale for the quality of data in this context. Traditional methods can be used to validate the game. Thereby, psychological realism, process validity, and structural validity, are all important. Given the lack of an objective measurement scale, face validity will play an important role, when one wants to assess the quality of the data. In general, the method is not directly useless in case the realism of the generated behaviour is affected. In case, for example, there are only very limited game plays possible with the actual stakeholders, a game can be played with non-stakeholders. Despite that this potentially decreases the realism of the output, it still can be very useful, e.g. to generate a diverse spectrum of strategies. However, the risk remains that the actual stakeholders structurally behave in a different way.

C. Playability

Another line of research should go out to the consequences for the game itself. Obviously, the focus of the game is on simulating realistic behaviour, but this may be not entirely at the expense of the game's playability. This means, the game as a whole, but also for each individual player or role, should be in balance. Also, an intrinsic motivator to play the game, e.g. a fun-factor or a learning experience, should be pursued. More research should be done to the potentially negative effects of these factors on the validity of the data collection tool.

Furthermore, it is reasonable to assume that not all types of real-world variables can be represented in a game. With experience and creativity a lot is possible. However, additional research should be done to examine whether there are structural exceptions (e.g. categories of artifacts that cannot be represented), or to compose guidelines. A variable that may fall in this category is electricity use on consumer level, since electricity is (in part) essential for living, and it is used indirectly.

D. Feasibility on the long term

Provided that the proposed data collection tool is useful for the support of the design of an agent-based model, it is useful to look forward to the long term feasibility. As we have discussed above, it is hard to determine whether the use of the data collection tool is sufficiently useful. Both the costs and benefits are hard to predict. A possibility to increase this feasibility is to decrease the costs of the tool. It is expected that structural research on this topic dramatically can decrease the development costs of the data collection tool. As the method is frequently used, either successfully or unsuccessfully, the usability of specific game elements becomes clear. A structured design framework can be developed, that contains a variety of elements that can be implemented in a game. Preferably, this framework is linked to an online database so that it is easily accessible and new knowledge can be implemented and shared very efficiently. Ideally, the model design phase of a new game will eventually consist of the quick selection of a number of suitable game elements. However, in practice the modelling process needs to be customized to some extent. Still, the framework has the potential to reduce the modelling time and costs significantly.

A similar framework can be developed that contains existing games, or descriptions and references to such games, in order to facilitate the game selection process. Furthermore, the results and output of games that have been used as a data collection tool (including rules that have been developed based on these games) can be implemented. Also these aspects have the potential to significantly reduce the development costs (and increase the benefits, since the games can be re-used).

V. Conclusion

This article proposes a new, specific application for games, namely using them as a data collection tool to support the design of rules for agent-based models. A theoretical foundation has been provided for the joint use of these two methods, as well as the specific assumptions of the new method. In order to successfully develop the support tool, many research have to be done on this topic. A research agenda has been provided in order to come to the answers of the most urgent questions. These can be divided in four main lines of research:

- The practical applicability of the tool must be shown. This includes the development of a proof of principle to show the general applicability of the method, and also multiple studies that examine whether the tool is more or less suitable in different situations (i.e. different characteristics of relevant aspects, such as the type of game, system representation, or behaviour).
- The objective and relative usefulness of the tool must be shown. Studies should go out:
  - to examine the disturbing effect of unrealistic rules on the system-behaviour.
  - to show that agents show more realistic behaviour when the support tool is used, compared with situations in which the support tool not is used.
  - to assess the design and operational costs of the tool.
  - to examine thresholds for the quality of the data required for the tool to be useful.
- The effect of the support tool on the playability of the game must be examined. A successful tool requires players to start and keep playing, in order to generate data.
- The feasibility on the long term should be examined. It is assumed that, on the long term, the tool becomes more beneficial, since the development time and costs will decrease as knowledge and experience grow. Research should go out to design a fruitful way to stimulate collaborations and to bundle knowledge.

The full development of a feasible and usable tool to support the design of rules for agent-based models, still requires a significant amount of work. The research agenda, as proposed, is a challenging one, as many questions still need to be answered. However, the prospect of an additional tool for designers that supports the implementation of more realistic social behaviour, makes it worth striving for.

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