Using gaming as a data collection tool to design rules for agents in agent-based models

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A design framework

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Preface

This document is the main result of the master's thesis project I performed, at the final stage of the master's programme System Engineering, Policy Analysis and Management at the Faculty of Technology, Policy and Management at Delft University of Technology.

The past year, I have worked with a lot of dedication and enjoyment to this research, in which many of my scientific interests, namely agent-based modelling, complexity, human behaviour, and methodology, come together. The final product is an explorative study on using games, in order to make agents of agent-based models behave more realistically. Also, it is a tentative attempt to stress the importance of a decent social scientific basis in models that represent social behaviour.

In completing this thesis, I wish to thank my direct supervisors Paulien Herder, Igor Nikolic, and Geertje Bekebrede for providing guidance, feedback and support during my project. Although it turned out a true challenge for me, from time to time, to find a free spot in your busy schedules, our meetings were always very fruitful. Your critical, yet constructive attitude towards my work, encouraged me to go to next levels. Furthermore I'd like to thank Andrew Bollinger for his role during the first phase of my project. Although his role as a supervisor was no longer necessary due to major changes in scope, I appreciate the commitment he has continued to show. Also, I'd like to thank Casper Harteveld for replacing Geertje as a supervisor, during her maternity leave.

Due to the methodological nature of this work, I did not have an external employer. However, I was very happy and lucky to have the luxury of my own desk an the Energy and Industry section. This allowed me to learn a lot of new people during lunches, coffee breaks, and as office mates. During my time as a graduate student, there has always been a very positive atmosphere, in which cooperation and assistance were highly valued. Therefore, I wish to thank all my 'colleagues', from both the Energy and Industry section, and the Policy, Organization, Law and Gaming section, for all their practical and theoretical input I received past year. I especially would like to thank Emile Chappin, for the answer to dozens of questions, for the interesting discussions, and his optimism.

Finally, I must thank my family and friends for their support and concern during my master's thesis project, and also for the distractions from studying, which they offered me. These really kept me going! With regard to this thesis, I'd like to express my sincere appreciation to Esther, for her many suggestions for textual and scientific improvements, and to Frederique, for her graphical contributions to this work. Finalizing this project, marks the end of my time as a student in Delft. During this intensive period, full of new experiences, my parents were always of great support. Thank you, for your unconditional love and support, and for providing me the opportunity to do all the things I have done during this amazing time!

Merijn van Os
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Summary

Agent-based modelling is a popular and suitable tool for exploring the possible states of so-called socio-technical systems. 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 (De Bruijn & Herder, 2009). The quality of the model output strongly depends on the quality of the rules of an agent, i.e. the lines of code that describe how an agent behaves. Slightly different rules on agent-level, may lead to significantly different outcomes on system-level (Bousquet, Cambier, Mullon, Morand & Quensiere, 1994; Levine & Fitzgerald, 1992). Thus, valid rules for agents are crucial for a valid analysis of socio-technical systems as a whole.

When modelling a socio-technical system with an agent-based model, some agents represent social artefacts, and thus must simulate real-life behaviour. However, in many cases, rules that describe social phenomena, are not based on empirically tested, theoretical models, and agents display unrealistically simplistic behaviour (Jager & Janssen, 2003). This restricts the analysis with respect to social behaviour, and may even lead to an invalid system analysis. In earlier research it is suggested that gaming simulations can be used to improve the realism and diversity of agent behaviour. However, this application of games has not been examined extensively. This research aims to acquire insight in whether this application of games is possible and feasible. The central research question thereby is:

To what extent can gaming contribute to the definition of realistic behavioural rules for agents in an agent-based model, within the context of modelling socio-technical systems?

An extensive literature research shows several problems and challenges with agent-based modelling. These include fundamental problems with the currently used methods used for gathering information about realistic behaviour (i.e. interviews and literature research). Several characteristics of gaming can help to reduce some of these these challenges, providing theoretical evidence that there is a potential for synergy between the two methods.

Based on a structural comparison of the methodological processes of agent-based modelling and gaming, it appears that there are several possibilities in which gaming can contribute to the definition of realistic behavioural rules of agents. In this thesis we elaborate on using gaming as a data collection tool. The gap between global knowledge about how agents behave and the implementation of precise rules in models is large. In case games can function as a valid data collection tool, the collected data can function as a basis for rules, which helps to overcome, or at least to reduce, design and formalization problems.

When a game is used as a data collection tool, there are three basic requirements that must be met: one must be able to generate valid data, to measure the desired data, and to analyse the data. Several aspects with regard to fulfilling these goals, affect the validity and the costs of the data collection tool. Furthermore, choices within one design

(game design, design data collection, or design data analysis), may have implications, direct or indirect, on other design choices, both within that design and in the other two. This interconnectedness makes the design process of the data collection tool as a whole very complex. Neither the game, nor the data collection method, nor the data analysis method is per definition leading in the decision which is the most suitable design. Whether, and how much the data collection tool can contribute to the definition of realistic behavioural rules, is very context dependent.

The proposal for using games as a data collection tool, and the proposed design framework have been done solely on a theoretical basis. The development of a useful and feasible tool, however, should also have a decent practical basis. Therefore, this work should be seen as the first of many research projects on this topic. The lessons learned from the application of this tool can and should be used to improve the proposed design framework.

Contents

Chapter 1

Introduction

1.1 Background

Socio-technical systems as complex adaptive systems Our world consists of many socio-technical systems. 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 (De Bruijn & Herder, 2009). The interconnectedness between multiple artefacts, both within the technical and social networks, as well as between them, leads to a high complexity (Herder, Bouwmans, Dijkema, Stikkelman & Weijnen, 2008). Examples of socio-technical systems include power grids, transport networks, and residual heat networks.

Complex systems have been studied in many research fields that view systems in a slightly different way, e.g. Systems Thinking (Forrester, 1958), Chaos Theory (Gleick, 1988) and Complex Adaptive Systems (Holland, 1996; Kauffman, 1995). As a result different communities make use of different terminology to describe their properties. Van Der Lei, Bekebrede and Nikolic (2010, p. 383) reduce this ambiguity and overall conclude that "complex systems are characterized by diverse agents that interact in a dynamic network, that is open to the environment. This interaction results in an overall system that evolves and adapts to its environment". This is why these systems are often referred to as complex adaptive systems (CAS).

Holland, cited in Waldrop (1992), provides an operational definition of a CAS:

> [...] a dynamic network of many agents (which may represent cells, species, individuals, firms, nations) acting in parallel, constantly acting and reacting to what the other agents are doing. The control of a CAS tends to be highly dispersed and decentralized. If there is to be any coherent behaviour in the system, it has to arise from competition and cooperation among the agents themselves. The overall behaviour of the system is the result of a huge number of decisions made every moment by many individual agents.

Thus, within this perspective systems are dynamic, and they grow, evolve, and adapt to the environment to survive. This makes CAS a suitable paradigm for describing socio-technical systems, since it analyses the dynamics of the physical system and is able to deal with the adaptive characteristic of actors (Bekebrede, 2010, p. 32). In literature, the term socio-technical system is also associated with man-machine interfaces (e.g. R. Cooper & Foster, 1971), which do not necessarily have to be complex systems. To avoid ambiguity, in this thesis we will only consider those social-technical systems that behave like CAS.

CAS can be represented in three conceptual levels (Van Der Lei et al., 2010). The agent level describes the individual, lowest level entities of the system. Secondly, the network level describes the relations between all those agents. The third level, the system level, describes how the aggregate system behaves as a result of the first two levels, and the interaction with the environment. These levels are combined in a generic framework that clarifies relationships between the properties and different levels of complex systems. This framework is presented in Figure 1.1.

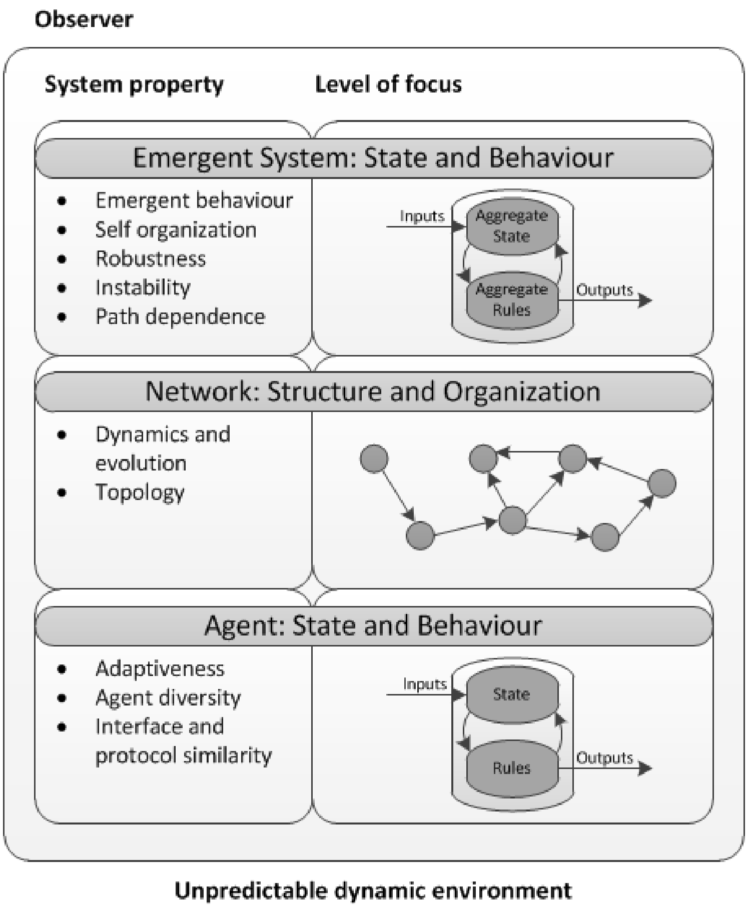

Figure 1.1: Complexity framework overview (Van Der Lei et al., 2010)

Analysing complex adaptive systems There are several reasons for analysing CAS. One of the main reasons is to provide insight in CAS for managers and policy makers, who try to guide them into more desirable states, e.g. an energy sector with reduced CO_2-emissions, or roads with less traffic jams. Multiple methods are available to model a CAS, including agent-based modelling (Epstein, 1999; Wooldridge, 2009), serious gaming (Abt, 1970; Mayer & Veeneman, 2002; Mayer, 2009), system dynamics (Forrester, 1958; Forrester & Wright, 1961) and discrete event simulation (Boer, Verbraeck & Veeke, 2002; Gordon, 1978).

However, not all of these methods are equally suited. An important notion comes from Nikolic and Dijkema (2010, p. 151). Based on Ashby's law of requisite variety and work of Gall (2002), they explain that when a CAS is modelled, not only the model must be a CAS, but also the process of creating the model must itself be a complex and evolving process: "We must start with a simple method for generating simple models, and evolve so that over time a complex method will generate complex models". This aligns with the view of Epstein (1999, p. 43) who stated that "If you didn't grow it, you didn't explain its emergence". Therefore, the modelling tool for describing a CAS, must have the main properties of a CAS. This means that they must be 1) multi-formal, 2) bottom-up and distributed, and 3) adaptive (Nikolic, 2009, p. 49-50). Nikolic concludes that agent-based modelling is the most suitable method, since it is the only method that meets all these properties.

Agent-based modelling is a tool which acknowledges that reality consists of many different entities acting in parallel and provides a way to describe these, their relations and interactions, and the overall system state (Nikolic, Dijkema, Chappin & Davis, 2009). When agent-based modelling is used to analyse socio-technical systems, there is no desired state or task that needs to be achieved, only an exploration of the system's possible states (Nikolic & Ghorbani, 2011).

1.2 Problem statement

An important warning, which applies to all modelling methods, is that "garbage-in leads to garbage-out". When the input of a model is of insufficient quality, so will be the model outcomes. Within agent-based modelling, model output emerges from the local rules of agents. These rules directly affect the behaviour on agent-level. Moreover, slightly different rules on agent-level, may lead to significantly different outcomes on system-level (Bousquet et al., 1994; Levine & Fitzgerald, 1992). Thus, rules of sufficient quality are crucial for a valid analysis of socio-technical systems as a whole.

Developing the local rules of agent-based models requires information about the decision making behaviour or agents, about how they forecast future developments, and memorize the past (Janssen & Ostrom, 2006). Some rules can be, be it in simplified form, determined objectively, e.g. based on physical laws and characteristics, or based on clear boundaries of the system. However, other rules, e.g. those that describe social phenomena, are harder to determine, because there the 'laws' that underlie those processes are less universal and clear.

An example of this problem can be found in modern mainstream economic theory, in which agents are "portrayed as fully rational Bayesian maximisers of subjective utility" (Selten, 2001, p. 13). However, important research has shown that this view does not align with how humans actually behave. Herbert Simon (1955, 1956, 1978), for example, argues that due to cognitive and physical restrictions, it is impossible to always strive for maximization. He proposed the notion of "bounded rationality", which is the intelligent use of one's limited cognitive resources in order to make a good decision. Simon (1956) suggests that people select alternatives by "satisficing", i.e. choosing the first alternative that meets all minimal criteria. Other research indicates that humans make decisions using all kinds of heuristics, possibly leading to several types of biases and errors compared to the optimal decision (Kahneman, Slovic & Tversky, 1982). In their own words, these heuristic principles "reduce the complex tasks of assessing probabilities and predicting values to simpler judgmental operations. In general, these heuristics are quite useful, but sometimes they lead to severe and systematic errors [compared with the optimal solution]" (Tversky & Kahneman, 1974, p. 1124). Basing rules of agents, that represent humans, on mainstream economic theories, thus, may be an unrealistic representation of the reality, since other decision mechanisms are used.

Jager and Janssen (2003) argue that simulation models, that describe social phenomena, in too many cases are not based on empirically tested, theoretical models of human decision-making. Also, the experience of the author is that in many cases, the behaviour of agents is modelled too simplistic. As explained, local rules may have significant influence on the model outcomes, which implies that insufficiently realistic rules, may affect the quality of the model and analysis.

1.3 Scope and research goal

In order to overcome the lack of sufficiently realistic behaviour of agents, it is suggested that gaming simulations can be used. "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" (Nikolic, 2009, p. 250). In this idea, gaming is used as a tool to generate and extract relevant behaviour from humans during game play. This data, then, can be used to draw up rules for agents in agent-based models. This application of games sounds promising, but has not been further developed.

The full development of a new method is an intensive and time-consuming process, which exceeds the scope of a MSc.-thesis. Therefore, this work should be seen as the first of many research projects to this topic. Before the method actually can be applied, and practical lessons can be learned from this, it is important to lay a decent theoretical foundation. In this thesis this will be done, mainly based on an extensive, and multidisciplinary literature study.

The main objective of this thesis is to acquire insight in whether it is possible and feasible to use games as a tool to increase realistic behaviour of agents for agent-based models. Given the lack of specific literature on the topic, the aim is to develop a theoretical framework that can be used as a support tool when a modeller is willing to use a game for this application. Furthermore, an important aspect of this thesis is to investigate the relevant aspects, when one is willing to use a game to support the design of more realistic agents.

1.4 Research questions and methods

The main research question following from the previous sections is formulated as:

> ***To what extent can gaming contribute to the definition of realistic behavioural rules for agents in an agent-based model, within the context of modelling socio-technical systems?***

In order to be able to answer this question adequately, several sub-questions have been formulated:

1. What is the foundation for using gaming to define realistic behavioural rules for agents?
2. In what way can gaming contribute to the definition of realistic behavioural rules for agents?
3. What are the most relevant aspects that must be considered when designing a game that can be used as a data collection tool?

The first research question concerns the scientific justification for the joint use of gaming and agent-based modelling. Although there is some literature in which combinations between computerized methods and gaming have been described (e.g. Barreteau, 2003), an extensive foundation is limited with regard to for joint use in general, and even lacking with regard to the definition of more realistic behaviour. The answer to this research question not only provides a justification for this thesis, it also provides insight in the reasons why modelling realistic behaviour is such a difficult task. This can serve as inspiration for fruitful combinations that might improve this modelling process. This research question will be answered by means of a comparison in which the benefits, weaknesses and design frameworks of agents-based modelling and gaming are compared.

The second question concerns the specific application of a combination of the two methods. As mentioned above, Nikolic (2009) suggested using players of a game as 'programmers' of agent-based models. However, no exact interpretation was given to this application. In what way can players 'program' agents? And is this the only way gaming can contribute to the definition of realistic behavioural rules of agents, or are more options possible? This research question will mainly be answered by structurally comparing the methodological frameworks of both methods. After the most important applications have been identified, the most fruitful method will be selected and elaborated on in the remainder of the thesis.

The third question concerns the design of the data collection tool. Several aspects are important because they affect the validity, costs and feasibility of the tool. Which aspects are these? And how do they relate to the design choices made during the design process? These questions will be answered by means of an extensive literature research, from several different disciplines, among which game design, psychology and artificial intelligence.

1.5 Thesis outline

This thesis is structured in the following way:

- **Chapter 2** gives a brief introduction of agent-based modelling. It explains the basics of the method, clarifies the most relevant terminology, and discusses the benefits, problems, and challenges of the modelling technique.
- **Chapter 3** explores the use of gaming to reduce the identified problems of agent-based modelling. It elaborates on gaming as a tool, and provides a theoretical foundation for the synergy between the two methods.
- **Chapter 4** presents the different ways in which agent-based models and games can be combined, and proposes to use gaming as a data collection tool for the support of the design of agent-based models.
- **Chapter 5** elaborates on those aspects of a game, that affect the generation of valid behaviour. It discusses limitations and trade-offs that have to be made in order to come to a solid design.
- **Chapter 6** elaborates on those aspects of data collection and data analysis methods, that affect the feasibility, validity and costs of the data collection tool.
- **Chapter 7** discusses the interconnectedness of the design aspects, related to data generation, data collection and data analysis. Furthermore it provides a general design framework for the design of a data collection tool. Finally, it briefly elaborates on the operationalization of this framework.
- **Chapter 8** presents the overall conclusions of this research, followed by a discussion on the results. This chapter also contains a personal reflection on this work by the author.

Chapter 2

Agent-based modelling to analyse socio-technical systems

This chapter provides an introduction to agent-based modelling, within the context of socio-technical systems. Section 2.1 outlines the main concept of the method and elaborates on the most important aspects and terminology. Also, this section further delineates the scope of this thesis. Section 2.2 elaborates on the most important benefits of agent-based modelling. In Section 2.3 some major problems and challenges of agent-based modelling are discussed. Finally, the most important aspects of this chapter are summarized in Section 2.4.

2.1 Agent-based modelling as research tool

Agent-based modelling is a simulation modelling technique centred around the concept of agents and their interactions (Nikolic, 2009, p. 51). The most basic explanation of an agent comes from Stuart Kauffman, who describes it as "a thing that does things to things" (cited in Shalizi (2006, p. 35). Shalizi (2006, p. 35) expounds that an agent is a "persistent thing that has some state we find worth representing, and which interacts with other agents, mutually modifying each other's states". Furthermore, in his definition Jennings (2000) mentions the capacity of an agent to be flexible and autonomous in order to meet its objectives.

With these characteristics in mind, an agent-based model (ABM) is "a collection of agents and their states, the rules governing the interactions of the agents and the environment they live in" (Shalizi, 2006, p. 35). The central experiment with an ABM 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 (Epstein, 1999). Thus, agent-based modelling is a bottom-up method, from the lowest practical level, in an environment in which many agents, all with their own goal(s), act in parallel. ABMs can be considered as a laboratory for capturing evolving systems in models, and can be used as a playground for scientists and practitioners to explore emergent outcomes of the interaction of a set of agents (Chappin, 2011).

2.1.1 States and rules

Basically, the structure of an agent consists of *states* and *rules* (Axtell, 2000). Nikolic (2009, p. 289) describes the state of an agent as:

> a specification of the particular collection of parameters that defines an agent (Wooldridge & Jennings, 1995). The state *is* all of the relevant information that gives it its identity. Based on the current state, the inputs and the available behavior, the agent will perform some action, causing an output to happen. It is the set of information about what this agent is at this moment.

A state can be on a discrete scale, e.g. the state of a light switch which can be either on or off, or on a continuous scale, e.g. the temperature of an agent. Moreover, states can refer to unobservable aspects, e.g. the amount of trust in another agent, or observable aspects, e.g. buying behaviour of a consumer.

Furthermore, Nikolic (2009, p. 289) provides a description of the rules of agents:

> Rules describe how the different inputs and internal states are translated to outputs and new states. Holland (1996) calls rules the "internal models" of agents. [...] Rules of computer agents in models of complex systems are usually rational, based on the maximization of utility of some sort. However, there is no requirement of rationality for agents. Agents can act irrationally, if given such rules. However, they cannot act *illogically*, given that they are computer entities. Actors (humans) can act rationally, irrationally or even illogically.

A semantic example of a rule, inspired by the *Consumer Lighting Model* (Chappin, 2011), is the decision of a consumer to buy a new CFL to light the house, when the old one has broken. In (pseudo)code this would look like:

```
If ConditionLight = 0,
then set Money to (Money - 5) and
set ConditionLight = 1
```

where *ConditionLight* is a dichotomous variable which indicates whether a light is broken or not, and *Money* is a continuous variable which indicates the amount of money a consumer has. In this example a new CFL costs 5 Euro. Note that this rule affects both these states.

With the definition of different rules it is possible to model multiple types of actors, as well as different subgroups within one type of actor. Some consumers of lighting, for example, may select a suitable product based on its lifetime. However, other consumers base their choice only on the type of lighting and the price. With different rules for this decision, these two subgroups can be represented in a model. Furthermore, it is important to emphasize that two agents with identical rules may display different behaviour, since each agent has it's own personal states.

Rules always consist of two parts: a condition, which specifies when a rule will be executed, and an action, which specifies the consequence of the rule firing (Gilbert & Terna, 2000). Multiple type of sources for a condition can be identified. In Figure 2.1 four different categories are specified, that can function as condition for the rule that affects state 2 of agent 1 (dotted line). The first category consists of internal states of the same agent. These can be both observable and latent states. The second category consists of internal states of another agent. This can be any type of agent and does not necessarily need to be the same type as agent 1. Note that these states do need to be (directly) observable by agent 1, and that the values are objectively perceived. The third category of input variables is observed behaviour of agent 2. This category is more subjective than the second category, since it is not guaranteed that agent 1 observes all relevant behaviour of agent 2, and it does not know which motives (i.e. states) drives this behaviour. The forth category is the external environment. These are variables and states that are not modelled as agents, because they are not (significantly) influenced by other subcomponents of the model. This category also includes time. Often rules consist of multiple variables from one or more categories. Theoretically, every combination of variables is possible. In practice, the number of variables per rule is rather limited.

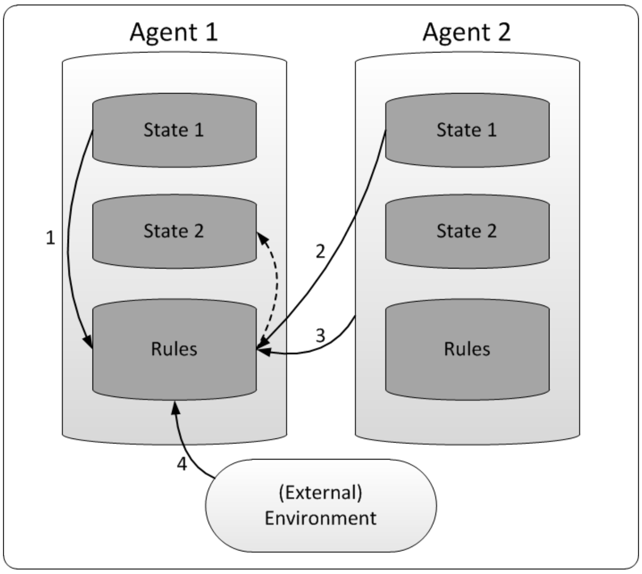

Figure 2.1: Different categories of input-sources for a condition

2.1.2 Simple and rich behaviour of agents

Agent-based modelling is a technique that is used in many research fields, among which psychology (Guastello, Koopmans & Pincus, 2009), biology, economics, and organization management (Macal & North, 2010). The specific applications of ABMs differ widely between these fields, and vary from very abstract to very case-specific. Initially, agents' behaviour was modelled by few and simple rules, in order to model complex phenomena. A classic example is the *Boids Model* by Craig Reynolds (1987). This model shows that the seemingly organized behaviour of bird flocking, can be simulated through the use of three simple, local rules of behaviour that are executed by each individual bird. Thus, flocking behaviour is not coordinated by any single bird, but *emerges* through the collective behaviour of all the birds.

More recently, ABMs have been developed which aim to explore future states of systems, i.e. provide insight in emergent system behaviour. In general, these models contain several different types of agents, but the total amount of agents is rather limited. Furthermore, these agents show more 'rich' behaviour, and, as a consequence, contain more, and more complex rules. An example includes the *Power Generation Model* (Chappin, Dijkema & Vries, 2010), in which the effect of carbon taxation and emission trading on CO_2-emissions is modelled. This thesis will focus on the latter type of ABMs.

2.1.3 Agent-based models and multi-agent systems

Literature dealing with agents and agent-based models, contains a substantial overlap in terminology and methodology with the concept of multi-agent systems (MAS). However, despite the fact that these fields are related to some extent, there are some important differences which cause MAS methodologies not always to be suitable for ABM purposes

(Nikolic & Ghorbani, 2011). Also, terminology of these two fields is often, but incorrectly, used interchangeably (Nikolic, 2009).

In this thesis we specifically adhere the agent-based modelling methodology. There are many different visions on the exact difference between ABMs and MAS. For consistency, we apply the view of Nikolic and Ghorbani (2011), who have identified four important differences. On the one hand, the goal of ABMs is to explore the (emergent) system-behaviour, arising from agent interactions. The goal of MAS, on the other hand, is to create an agent-based software system that would be used to a particular control problem (e.g. traffic control). The different goals lead to a focus on efficiency of the system for MAS, while agent-based modelling is more aimed at representing real-world entities in a realistic way. Furthermore, the scale and diversity of MAS are generally more limited, compared with ABMs, as a consequence of which MAS are better understandable.

2.2 Benefits of agent-based modelling

To evaluate the benefits of a modelling method, the purpose of the method should be kept closely in mind. In this research we aim to model socio-technical systems, that can be described as complex adaptive systems (CAS). As is mentioned in the previous chapter, agent-based modelling has all the properties of a CAS, and, therefore, is suitable to model a CAS (Nikolic, 2009). These properties allow the system representation of socio-technical systems to be high, because there is a good correspondence between between the structure and dynamics of the model and the reality (Nikolic & Dijkema, 2010). Also, the possibility to make multiple types of heterogeneous agents, all with their own personal goals (Axtell, 2000), aligns well with our view on socio-technical systems.

Furthermore, the bottom up nature of ABMs, results in a natural description of a system (Bonabeau, 2002). When one wants to describe how a traffic jam occurs, for example, it is more natural to describe how cars behave on a road, than to come up with equations that describe the dynamics of the density of the cars (cf. Bonabeau, 2002). This contributes to an intuitive understanding of the models by stakeholders, users and modellers (Nikolic & Dijkema, 2010). This contributes, in turn, to the extent in which the models are accepted and used.

In their article, Borshchev and Filippov (2004) compare agent-based modelling with several other modelling methods, among which System Dynamics and Dynamic Systems. They indicate three major advantages of ABM above the other methods. Firstly, agent-based modelling enables to capture more complex structures and dynamics. This makes this technique more powerful than the other modelling tools. Secondly, ABMs are easier to build when there is little or no knowledge about the global interdependencies. Models can already be built when there is a global perception of how the individual participants of the process behave. A third advantage is that ABMs are easier to maintain, because refinements normally result in local, not global changes.

Another advantage of agent-based modelling is its flexibility (Bonabeau, 2002). This can be observed along multiple dimensions. It is, for example, easy to vary the size of a model by adding or removing agents. Furthermore, an ABM provides the possibility to change levels of description and aggregation. Multiple types and subgroups of agents can be created, which can coexist in a model. Another dimension of flexibility is the ease with which agents complexity can be tuned. Because of the local rules, the behaviour, states, interactions and ability to learn of an agent can easily be modified. This also results in the possibility to re-use source code from previous models (Van Dam, 2009).

The bottom-up nature and the local rules of ABMs result in another advantage that is specifically important within the scope of this thesis. Agent-based modelling allows for the explicit capture of bounded rationality (Axtell, 2000), and the role of non-monetary factors in decision making. Any type of variable that has been defined in a model, can be a criterion for an agent's decision.

A last advantage that is discussed here, is found in the fact that agent-based modelling is a computer model. This makes it possible to replicate results, and, once a model is established, virtually an unlimited number of experiments can be performed. This allows that any (relevant) combination of settings can be tested, and any pattern of behaviour can be analysed (Meijer, 2009, p. 37-39).

2.3 Challenges and problems with agent-based modelling

Although agent-based modelling is considered as a suitable method to analyse socio-technical systems, some major challenges and problems have to be overcome, in order to come to useful simulations. Like many scientific computer models, an ABM tries to capture real world phenomena with mathematical symbols. This is a challenge given the large diversity of variables, actions and goals, and will, per definition, lead to a model in which social rationality (e.g. a political agenda) is under-represented (Mayer, 2009; Bekebrede, 2010, p. 12). Autonomous agents and local rules allow us to take social aspects into account to a certain level. However, this will always be a significant simplification compared with the capricious and rich behaviour of actors. Respecting this fundamental simplification, two main challenges can be identified. The first challenge is to convert real word phenomena to source code for ABMs. The second challenge is to demonstrate that these local rules are sufficiently realistic representations of the reference system, given the purposes of the model. These two aspects, the rule design process and the validation of the model, will be discussed in Section 2.3.1 and Section 2.3.2, respectively.

2.3.1 The design of rules

Rule design is an important part of the design process of an agent-based model. It consists of several iterative steps: system analysis, model design, and detailed design (c.f. Nikolic & Ghorbani, 2011). The first two steps consider the question 'what' has to be modelled. The last step also considers the question 'how' this formalization should be done, given the characteristics of the variables that have to be modelled, and the available concepts of the modelling language that is used. An elaboration of these modelling steps can be found in Appendix A.

In order to model (elements of) a system, the relevant information must be extracted from that system. Currently, the design of (the behaviour of) social entities in agent-based modelling, is mostly based on interviews and literature studies (Nikolic & Ghorbani, 2011). Although these methods can be very useful and insightful, they entail some important problems.

Interviews as source of information When interviews are used as a source of information, the modeller is dependent on the information that the interviewee provides. This information does not necessarily have to be correct. One of the main reasons incorrect information is provided, is because interviewees are biased to their own perspective. Generally, this leads to a description in which relatively too much focus lies on (and too much weight is attached to) ones own tasks, known as *déformation professionnelle*. Another reason for providing incorrect information is because people often do not know or realize how they actually behave (Robson, 2002). Many decisions are made subconscious, based on intuition or heuristics. When one is asked to describe their decision making behaviour, this appears often a very difficult task and is biased to how people should have made their decisions according to the norms. These problems can be partly overcome by interviewing many people, so that a more nuanced picture emerges. However, this is only possible as long as there are multiple interviewees available, and they are willing to cooperate. Furthermore, interviewing stakeholders is a time-consuming operation

The reasons described above all assume that the interviewee is unaware of the fact that he or she is providing incorrect information. However, this may also happen consciously and intentionally. There are several conceivable reasons to provide strategic information during an interview, e.g. because direct competitors are involved and may get access to this information, because one is not willing to harm existing relations, or because one tries to influence the model outcomes. Another reason for intentionally providing incorrect or incomplete information includes embarrassment for ones own behaviour, e.g. because it deviates from the norms.

Literature as source of information Also using a literature study as a source of information for model design entails several problems. Two obvious, but nonetheless important dangers can be indicated. Firstly, there is the potentially biased perspective of the modeller. In case a modeller has certain ideas about the system behaviour on beforehand, this may cause him/her to look for self-confirming research. A second danger is the misinterpretation of conclusions found in literature. This includes paying insufficient attention to the discussion sections of research. This risk increases, when one is not familiar with the field of research. However, with thorough research the effect of these two dangers can be reduced to a minimum.

A more fundamental problem is the analytical nature of research within social and behavioural science. 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 (Hofstede & Meijer, 2008). 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 agent-based modelling, context is very important. Products and models are designed and evaluated in a specific context of use (Hofstede & Meijer, 2008). 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. Obviously, there are plenty examples of detailed, more applied research within these domains, in which a clear context is defined. However, given the unlimited number of potential research topics, the probability is small that the specific research, that is required to design valid rules for agent-based models, already has been performed.

To clarify this problem, we provide an example based on the *Consumer Lighting Model* by Afman and Chappin (described in Chappin, 2011). This model has been developed to explore the effects of different types of government policy on the transition from current types of lighting, such as glow bulbs to low-electricity consumer lighting, such as LED and CFLs. One of the components that has been modelled is the consumers' opinion about the different types of lighting. This opinion is subject to change, based on either a positive or negative experience. The changes in opinions changed with +0.1 and -0.3, after a positive and negative experience, respectively. This difference is based on the 'psychological law' that the effect of negative experiences outweighs the effect of positive experiences. Although it is plausible that this law is applicable to consumer lighting, the values that are used cannot be substantiated by it (and this is, therefore, not done). This raises serious question about the validity of this rule.

Another problem with regard to the design process of rules is the formalization of ill-defined concepts. There are many concepts, especially within social sciences, for which there is no general agreement on their exact nature and/or structure. This causes problems for modellers who want to implement such concepts in their model. For example, Nikolic and Ghorbani (2011) rightly raise the question whether trust, is a number from 0 to 100, or an elaborate hierarchically structured construct consisting of many other objects and their relationships. If the latter is the case, the definition of the variables from which the construct is composed, may, in turn, lead to the same formalization problem on another level (Van Os, 2011b). It is important to stress that within this formalization process, design choices must be made, which may have significant influence on an agents' behaviour, and thus may affect the emergent behaviour of the model.

2.3.2 The validation of agent-based models

The validation of a model concerns the question whether a model provides an accurate representation of the behaviour of the real-world system, that it is intended to represent given the intended purposes (Sargent, 1998). Since the model output is the result of both the system analysis and its formalization into a model, the validation is automatically a check, whether the formalization is (sufficiently) representative. Traditionally, models are validated by means of comparing model outcomes with observed reality. However, since we are interested in examining future states of social-technical systems, there are no real world states to compare with. Therefore, validation of ABMs in the traditional sense is not possible and must be done by other means. This makes agent-based models, in general, relatively hard to validate. Commonly used methods include historic replay, face validation through expert consultation, literature validation and model replication (Nikolic, Van Dam & Kasmire, forthcoming). Overall, these methods do provide insight in the validity of a model, but all have some obstacles. For example, there may be no proper comparison material, because the conclusions are context dependent or because the literature is simply not available. When a model is validated by means of model replication, the reference system is replicated by another ABM with a different system decomposition, or with another modelling method. The output of these models, then, is compared. This is a suitable method to validate a model, but it is time consuming and expensive.

2.4 Conclusion

From this chapter, we can draw the following conclusions:

- Agent-based modelling is a bottom-up modelling method, centred around the concept of agents and their interactions.
- Agent-based models are suitable for representing evolving systems and can be used to explore (emergent) system behaviour.
- Representing social behaviour in agent-based models is a fundamentally difficult process.

- The current methods on which rules, that represent social behaviour, are based, entail some problems:

  Interviews
  - An interviewee may be biased.
  - An interviewee may be not aware of his own decision making behaviour.
  - An interviewee may intentionally provide incorrect information.

  Literature
  - Due to the analytic nature of social and behavioural science, there is a gap between the available information, which is context-independent, and the required information, which needs to be context-specific.
  - Some concepts are ill-defined, which makes them hard to formalize for a computer model.
- Due to the explorative nature of agent-based models, they need to be validated by means of non-traditional methods.

Chapter 3

Exploring the joint use of agent-based modelling and gaming

In the previous chapter, we elaborated on agent-based modelling. We identified some problems and challenges with regard to modelling social behaviour. In this chapter, inspired by the suggestion by Nikolic (2009), we will explore the joint use of agent-based modelling and gaming. In order to do this we first need to elaborate on gaming. In Section 3.1 we discuss and clarify the terminology of the method. Section 3.2 elaborates on gaming as a tool for purposes other than entertainment. In Section 3.3 the potential synergy between agent-based modelling and gaming is made explicit. This is done based on the challenges and problems of agent-based modelling identified in the previous chapter. Subsequently, in Section 3.4, some currently used combinations between computerized models and gaming are discussed. Finally, in Section 3.5 the conclusions of this chapter will be provided and the first research question of this thesis is answered.

3.1 Clarifying terminology

In literature, there is much ambiguity surrounding gaming and related concepts. There is, among other things, no generally accepted definition of games. In this section we define the relevant concepts related to gaming, as used consistently throughout this thesis. In Section 3.1.1 and Section 3.1.2, we define the concept of games and serious games, respectively. An extended version of these sections, including an elaboration on how we have come to these definitions, can be found in Appendix B. Section 3.1.3, elaborates on the difference between gaming and simulation.

3.1.1 Games

In this thesis, games are considered as a subset of play. This implies that some activities of play can be labelled as games, while others cannot. The difference between play and game is a subtle one. In some languages among which, German, French and Dutch, the words for both concepts are identical. This has led to some confusion in defining both concepts. Many attempts have been made to define a game, but none remained uncriticized (Salen & Zimmerman, 2004; Schell, 2008). In introducing and elaborating on family resemblance, Ludwig Wittgenstein (1953) even shows that there are fundamental difficulties in defining a game. Salen and Zimmerman (2004) structurally compared all elements of eight definitions of games, and found that no single element appeared in all of the definitions. There appeared only a majority agreement for the notion that games have rules and goals. Based on the analysed definitions, Salen and Zimmerman (2004) formulated an own definition of games:

> A game is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome.

This definition does not offer a perfect demarcation criterion to make a distinction between games and play (the authors do not pretend it does). However, it covers the most important elements derived from literature, and can function as a suitable working definition for this thesis.

3.1.2 Serious games

Given the topic of this thesis, another concept that requires some elaboration is *serious games*. As with games, literature does not provide us with a generally accepted definition (Susi, Johannesson & Backlund, 2007; Ulicsak & Wright, 2010). Clark Abt (1970) introduced the concept of serious games. His definition of such games was that they:

> have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement. This does not mean that serious games are not, or should not be, entertaining (Abt, 1970, p. 9).

In most definitions an educational purpose for the player is a central element, and a requirement for games to be classified as serious games. However, for several reasons this is considered to be too narrow for this thesis (see Appendix B). Therefore, we have composed a more operational definition:

> Serious games are games that contribute to the achievement of a defined purpose, formulated by the game's designer, other than pure entertainment (whether or not the user is consciously aware of it).

In this thesis, all games that are considered are within the context of one main purpose, namely the definition of behaviour for agents in agent-based models. All these games, thus, fall within our definition serious games. In the remainder of this thesis it suffices to speak of games, to avoid confusion with serious games that have an educational purpose (cf. Abt, 1970).

3.1.3 Gaming and simulation

The previous sections, and Appendix B, only cover a fraction of the vast body of literature about games, and indicate that many concepts within this topic are ambiguous. The discrepancy between the definitions of play, games and serious games contributes to the use of different terminology surrounding gaming. The terms simulation, game, simulation game, gaming simulation and gaming/simulation all appear in literature (Klabbers, 2009; Meijer, 2009). In some cases, these are different terms for the same concept. In other cases, an explicit distinction is made between two or more of these terms based on specific characteristics, e.g. Duke and Geurts (2004, p. 35-41) and Bekebrede (2010, p. 65-69).

In this thesis, the term *simulation* is defined as studying the effects of a predefined variable on some key variables in a model that represents (a part of) a real-world system. This definition is a broadening of the definition provided by Meijer and Hofstede (2003), who considered only the effects of *human* behaviour and decisions as part of simulation.

However, this excludes model runs of, for example, agent-based models, which, in our opinion, can be considered as simulations as well. A *gaming simulation*, then, is a simulation of (a part of) a real-world system in the form of a game. *Simulation games* are considered as a subcategory of games. This type of games is characterized by a clear connection with reality (c.f. Duke & Geurts, 2004). When we mention *gaming* in this thesis, we refer to using a game for a simulation (i.e. the usage of a gaming simulation).

3.2 Gaming as tool

This section elaborates on gaming as a tool for purposes other than entertainment. In Section 3.2.1 some basic concepts of games as tool are discussed. In Section 3.2.2 we focus on one specific application of gaming, namely as a research tool.

3.2.1 Exploring the method

As we have seen in the previous section, gaming is using a game to simulate a real-world system. It can be seen as an alternative 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 be random participants, but also be the actual stakeholders of the real-world system (Barreteau, 2003). "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" (Meijer, 2009, p. 26). This makes gaming suitable for modelling the social artefacts of a system.

Based on work of Gibbs (1974), Meijer (2009) subdivides the structure of a game into four elements: roles, objectives, rules, and constraints.

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* (Bilsen, Bekebrede & Mayer, 2010), 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* (Maxis Software Inc., 2003). 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 (Gibbs, 1974).

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" (Meijer, 2009, p. 25).

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 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 game. Stahl (1988) makes a useful distinction between rigid-rule games and free-form games:

> In *rigid-rule gaming* all of the institutional assumptions in the model of the game situation are supplied by the game constructor. Hence, all of the

> rules of the game are defined before the game starts, often in the form of a computer program. Thus the outcome of every possible combination of players' decisions is defined precisely.
>
> In *free-form gaming* at least some of the institutional assumptions are supplied by the game players as the game proceeds. Thus, the players to some extent invent the rules as the game goes on. As the consequence, the outcome of a particular decision might, for example, emerge from discussions among the participants.

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.

Besides entertainment, there are many serious purposes for which games can be used. Figure 3.1 shows the most important applications. It is very well possible that a game has multiple serious purposes. In general, these serious purposes can be divided into three main categories, games to improve policy, learning and research (cf. Mayer & Veeneman, 2002; Meijer, 2009). In the next subsection, we zoom in on the latter category, to see what we can learn from them.

Figure 3.1: Different serious purposes of games (Van De Westelaken and Peters, 2011)

3.2.2 Gaming as tool for scientific research

There are several applications in which games 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 gaming simulation, is one of many methods that can be used to simulate such systems, and investigate the research questions (Van De Westelaken & Peters, 2011).

However, the use of games in an experimental context is not limited to the simulation of inaccessible or future systems. Games are frequently used in both experimental, and behavioural economics (Camerer & Loewenstein, 2004). The data collected in these games is used, for example, to design, improve or validate economic theories or to analyse strategic decision making behaviour (Kahneman et al., 1982). 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 (2008) argue that it is also possible to use data from gaming simulations in quantitative empirical methods, when more context (and thus more 'disturbing variables') is present. A requirement, then, is that there are 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" (Duke, 1974, p. 78-79).

Also, games have been used to gain insight in socio-technical systems, e.g. *Pro Rail* (Meijer, Mayer, Luipen & Weitenberg, 2011), and *SimPort-MV2* (Bilsen et al., 2010). As we have mentioned earlier, when a research tool is used to model a CAS as a whole, it is required to have the properties of a CAS itself in order to give a good representation (Nikolic & Dijkema, 2010). Bekebrede (2010, pp. 72-82) explains that some, but certainly not all, games can be seen as a CAS. To be a complex game, a game must 1) consist of multiple diverse elements, 2) have flexible rules that structure interaction and show evolution and adaptation, and 3) represent the consequences of players' decisions and of emerging processes in the final state. When these conditions are met, games can be used as a tool for modelling CAS.

The last application that is described here, is one in which players literally and directly contribute to science. Actual research questions and hypothesis are used as inspiration for puzzle games. When these games are played, the problem solving intuition and competitive nature of humans are used to tackle these problems. The game *Foldit* is an excellent example for this type of games. This game is concerned with protein structure prediction, an important problem within biology (S. Cooper et al., 2010). Because of a huge number of degrees of freedom this is a computational challenge. In *Foldit* players compete and collaborate to find the most optimal protein structure. In turns out that experienced players are better 'folders' than computers are. The search strategies of these players are used to improve existing algorithms. In a later stage, the game may be used for 'protein design' as well, which means that players contribute to research to prevent or treat diseases like cancer, or HIV/AIDS (Harteveld, 2011).

3.3 Synergy between agent-based modelling and gaming

Based on the characteristics of both agent-based modelling and gaming, there is a theoretical ground for synergy between both methods. In Section 2.3, several challenges and problems with agent-based modelling have been presented. One of the main difficulties is that it is hard to simulate realistic behaviour. This is in part due to a fundamental simplification from real-life behaviour to a computer model, and in part due to problems concerning the methods that are used for the design of ABMs. As we will see, gaming is a method that can be used to overcome those difficulties to some extent.

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 with games. In this situation games form the context of the experiment. The game designer has a large amount of control over the environment and the structuredness of the game (Meijer, 2009). Given the adjustability of roles, rules, objectives and constraints, it is possible to simulate the reference system, or to implement the relevant context of the behaviour. 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.

Thirdly, gaming simulations, unlike questionnaires, interviews and computer simulations, provide the possibility to examine actual behaviour (Meijer, 2009). Humans do not always correctly indicate how they behave, e.g. because they do not know (precisely) what they do, or for strategic reasons. Directly observing the simulated game as a source of information decreases this bias.

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 to fill in the gap between an analytic analysis of behaviour and applied model-design, as it functions as a context specific experiment.

3.4 Current combinations between computerized models and gaming

We are not the first to suggest a combination between computerized models and games. Figure 3.2 shows several possibilities to combine models and games. Barreteau (2003) differentiates two keys on which the combinations can be classified: parts of the shared conceptual model and concomitance of use. The first key determines whether the model and the game have the same underlying conceptual model, i.e. a set of roles and rules played either by a set of humans or by a set of codes (cf. Hanneman, 1995). In practice this is a criterion with a continuous scale, however these two extremes emerge from analysed experiments (Barreteau, 2003). The second category differentiates between applications in which the computer model and game are used in parallel or one after another.

	Different underlying conceptual model	Same underlying conceptual model
Model and game are used within parallel processing	• Model supports game enforcement • Model included in the game • Game as a communication mean between model and reality	• Competition
Model and game are used one after the other	• Game to learn how to use model	• Model to repeat the game • Game to validate the model • Model to support game design • Game to support model design • Co-construction of model and game • Model as benchmark

Figure 3.2: Classification of the categories of joint use of a computerized model and a RPG according to the sharing of conceptual model and the relative timing of use. Adapted from Barreteau (2003).

In the previous section, we indicated that games can be used to overcome some difficulties concerning the modelling of agents. We are specifically interested in improving the quality of (the behaviour of) agents, by making them more realistic. This implies that games will be made part of the design process of ABMs. The two methods are, thus, used alternately, whereby the game serves the model. Furthermore, the same reference system is modelled using both methods. They have, thus, at least partly, the same underlying conceptual model. Figure 3.2 shows that within this quadrant there are still several joint uses possible. In this thesis we focus on using games to support agent design. In our opinion, this includes the validation of agents.

Within this context several methods already have been developed. In the next sections, we discuss three of them: The MAS/RPG methodology, and agent-based participatory simulations, which are both forms of participatory modelling (Section 3.4.1, and crowdsourcing games (Section 3.4.2).

3.4.1 Gaming as a form of participatory modelling

Participatory methods can be defined as "methods to structure groupprocesses in which non-experts play an active role in order to articulate their knowledge, values and preferences" (Van Asselt & Rijkens-Klomp, 2002, p. 176). One of the applications that can be differentiated is participatory modelling, which refers to active involvement of stakeholders in a modelling process. Reasons to involve stakeholders are to improve mutual understanding between the model-builders and model-users (Van Asselt & Rijkens-Klomp, 2002) or to bring relevant knowledge about agents, rules of behaviour and target domain into the model (Boero & Squazzoni, 2005; Pahl-Wostl, 2002).

Multiple types of participatory models can be identified, distinguished by the level of participation involved (Parker, Manson, Janssen, Hoffmann & Deadman, 2003). Types that can be identified include stakeholder participation in model-building and stakeholder participation in model-running. In this last form stakeholders act as agents in the model. A game can function as an environment to facilitate this form of participation (Barreteau, Bousquet & Attonaty, 2001). Two of such methods are discussed in more detail.

MAS/RPG methodology The MAS/RPG (Multi-Agent Systems/Role-Playing Games) approach (Barreteau et al., 2001) is the methodological coupling between (role-playing) games and agent-based simulations. "The initial idea is to consider the RPG as a living MAS in which players are the agents and the set of roles is the rule base" (Barreteau et al., 2001). The MAS/RPG approach can be considered as a combination between these tools and field observations, and is represented as a cyclic process (see Figure 3.3).

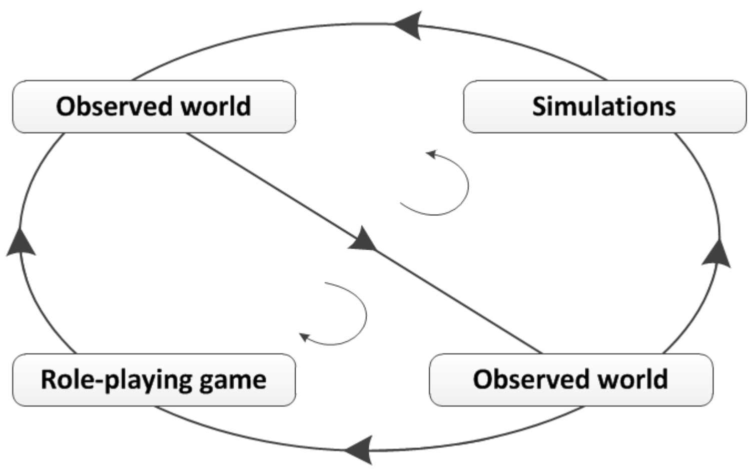

Figure 3.3: The MAS/RPG process (adapted from Barreteau et al., 2001)

In practice, however, the first step of this method consists of creating an agent-based model of a given phenomenon, after which this model is converted into a game (Guyot & Honiden, 2006). This step involves many simplifications, e.g. the number of agents, the number of rules and some parameters (Barreteau et al., 2001). Furthermore, the game is tailored to provoke specific reactions from the participants. There are various interfaces possible between the RPG and the MAS (Guyot & Honiden, 2006).

Agent-based participatory simulations Agent-based participatory simulations are an evolution of the MAS/RPG approach, in which computers are further integrated into a RPG (Briot, Guyot & Irving, 2007; Guyot & Honiden, 2006). In this method participants actively take control of an agent, and behave as if they were part of the agent-based simulation. The participant, thus, can be understood as the control architecture of an agent. The methodological process is summarized in Figure 3.4. The terminology used in this figure, differs from the terminology that is used in this thesis, but the concepts are very similar. The target system is a certain delineation of reality, and similar to the reference system. The domain model can be compared with the end-product of the system analysis phase. The design model is an intermediate step of the formalization of the agent-based model. This step can be considered as an ideal (but not realistic) formalization, following from the domain model. The simulation model restricts this model, driven by the digital nature of the model and the need to adapt to the constraints and the goals of the experiments.

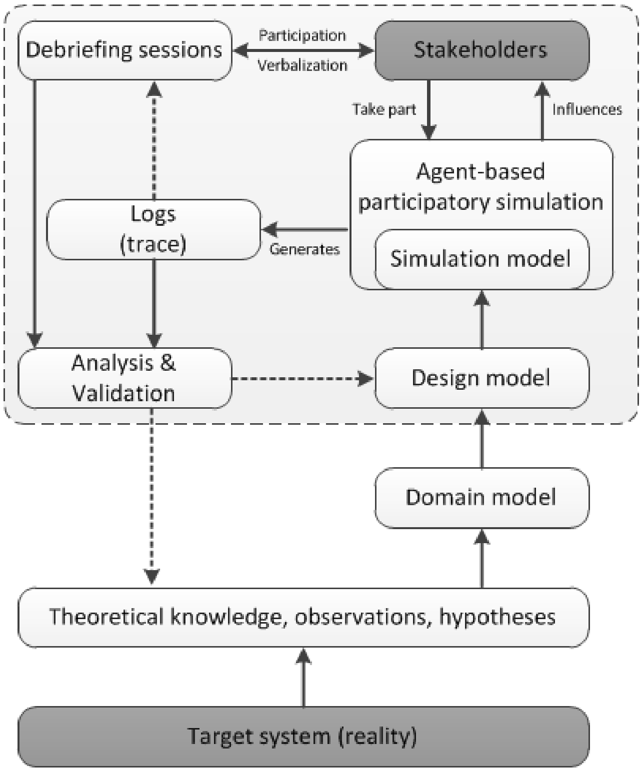

Figure 3.4: The participatory simulation process (adapted from Guyot et al., 2006)

Agent-based participatory simulations have some advantages over the MAS/RPG approach. The first advantage is that participants interact through a computer mediated interface. This allows simulations in which stakeholders are geographically distant. Another advantage of computer mediation, is that all actions and interactions can be easily recorded and processed. The results can be used to support participants and modellers to better understand the game and its dynamics. Thirdly, the gap between the agent-based model and the behaviour of the participants is decreased, since the game and the agent-based simulation are merged. Finally, because participants take part by controlling agents, it is technically simple to replace them by artificial agents when they cannot participate in the simulation (Briot et al., 2007).

However, with respect to the simulation of realistic behaviour this method has some potential disadvantages. Firstly, the behavioural space of the participants is restricted by the agent they control. The full potential of human players, namely, that they can put oneself into a role and show 'rich' behaviour, is not used optimally given these restrictions. Furthermore, this simplification causes a different cognitive load compared to the reference system, potentially resulting in different behaviour. Finally, the agent-based model is often a very abstract representation of the reference system. It can be questioned whether this context is suitable to trigger sufficiently realistic behaviour.

Despite these potential disadvantages, agent-based participatory simulations shows us a methodology in which games are used to 'program' agents with human behaviour, in order to make them behave more realistically. This provides inspiration for our own work, and offers confidence that games can be used to support the design of agents.

3.4.2 Crowdsourcing games

Games are also used as an application of crowdsourcing. This can be defined as "the act of a company or institution taking a function once performed by employees and outsourcing it to an undefined (and generally large) network of people in the form of an open call" (Howe, cited in Brabham, 2008). People can be stimulated to participate in a crowdsourcing project, e.g. by a small financial compensation or by a 'fun factor'. Every day millions of people spend time playing (online) games for their own entertainment. The idea behind crowdsourcing games is that the output of these can be valuable for other purposes. In this way people contribute to a useful cause, while enjoying themselves. Von Ahn and Dabbish (2004) pioneered within this field and developed the *ESP game*. In this game anonymous coupled players try to reach agreement on the content of different images, by 'guessing' what their partner will type. All words on which players reach agreement on, are stored in a database and used for labelling these images to improve online search engines. Von Ahn and Dabbish (2004) estimate that all images on the Web can be accurately labelled within a few months, when the *ESP game* is played as much as popular online games. Other examples in which human capabilities are used for serious purposes include *Foldit* (improving search algorithms for the most optimal protein structure, S. Cooper et al., 2010), *Major Miner* (labelling music clips, Mandel & Ellis, 2008) and *Galaxy Zoo* (classifying galaxies, Darg et al., 2010; Lintott et al., 2008).

A crowdsourcing game of particular interest is *The Restaurant Game*, by Jeff Orkin and Deb Roy (2007). *The Restaurant Game* is inspired by the field of artificial intelligence in their attempts to make agents, either robots or virtual agents, behave more like humans. The game tries to capture behaviour and dialogue from thousands of in-game interactions between humans, and to automate agents with this data (Orkin & Roy, 2009). Two players are anonymously paired and placed in a 3D virtual restaurant. They are assigned either the role of waitress or customer, and are given the vague objectives of earning money or having dinner, respectively. Players are allowed to chat with open-ended typed text, move around through the environment and interact with 47 types of objects through a point-and-click interface. Every object provides six interaction options: pick up, put down, give, inspect, sit on, eat, and touch (Orkin, Smith, Reckman & Roy, 2010). This apparent freedom leaves room for players to misbehave, and many of them do so. However, Orkin and Roy (2007) demonstrated that it was possible to collect data from thousands of game-players, and use it to learn statistical models of language and behaviour. "While many players do choose to deviate from the norm, their aberrant interactions wash away statistically when compared to the larger number of examples of typical language and behavior" (p. 11). Subsequent research has shown the first iteration of a case-based planning system, which automatically learns to imitate humans based on recurring patterns of behaviour (Orkin & Roy, 2009). Those gameplay traces are selected that best match with the observed interaction history.

In *The Restaurant Game* a very specific and familiar situation is simulated. The goal is to collect data, in order to reproduce the appropriate behaviour, which includes both actions and dialogue. The main goal of *The Restaurant Game*, thus, corresponds with our goal to make agents behave more realistically. However, an important difference can be identified with respect to the level of detail of the simulated behaviour. *The Restaurant Game* aims to gain insight in 'scripts' (cf. Schank & Abelson, 1977). These can be described as schemata, consisting of action sequences, roles for participants and objects found in a story or situation. These scripts help us to better assess and understand the world. When we read, "Sarah went to a restaurant. She ordered the daily menu. She left a large tip", we can infer that she also entered the restaurant, sat down at a table, communicated with the waiter, ate her food, and was pleased with it. By making these mental scripts explicit, and implementing them in a digital agent, realistic behaviour can be simulated when the appropriate script is selected.

Scripts, as they are formulated by Schank and Abelson (1977), are concepts intended to describe behaviour on micro-level. When modelling socio-technical systems, this level of detail is, generally, not required, or even undesirable. We are not interested, for example, in how a conversation between a customer and a waiter evolves (including the appropriate responses of both actors), but in the outcomes of this conversation, as a result of following scripts. This is, for example, the decision to order menu A, and not menu B, and the mechanisms on which the customer bases this decision. Therefore, our focus should not lay on identifying scripts. However, the principle of gaining insight in fixed patterns of behaviour, might be usable on a more abstract level. Whether principles for these 'meta-scripts' are the same as for scripts has not been studied. More research should be done to this topic.

Despite the differences in level of detail and the additional focus on language, *The Restaurant Game* provides an excellent example of how games can be used to extract behaviour from human participants, and provides us with inspiration for a methodology that is suitable for more abstract behaviour.

3.5 Conclusion

From this chapter, we can draw the following conclusions:

- Games can be used as a tool to simulate real world systems.
- The structure of a game can be subdivided into four elements: roles, objectives, rules, and constraints.
- There is a theoretical scientific foundation for using a game for the definition of realistic behavioural rules of agents.
  - Because humans, and not agents, make decisions, social complexity and social rationality play a more realistic role in gaming simulations, compared to computer models. This may result in more realistic states and outcomes with regard to the social aspect.
  - It is possible to perform experiments in which games function as semi-structured environment. The adjustibility of the game elements allows us to replicate the reference system, in order to deal with the context-specificity of behaviour.
  - Gaming simulations provide the possibility to examine actual behaviour.

- 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 to fill in the gap between an analytic analysis of behaviour and applied model-design, as it functions as a context-specific experiment.

Chapter 4

Games to support the definition of realistic behavioural rules

In the previous chapter we provided a theoretical foundation for combining agent-based modelling with gaming, in order to support the simulation of realistic behaviour. We showed methods in which computerized models are combined with games. However, these methods do not align well with our specific goal to let agents of agent-based models behave more realistically. In this chapter we examine the possibilities to use games specifically to fulfil this goal. We start in Section 4.1 by comparing the design processes of both methods. Based on this we examine in Section 4.2 how these design processes can be combined. We chose to focus on using games as a data collection tool for agent-based modelling, which we will elaborate on in Section 4.3. Section 4.4 elaborates on the decision whether or not to use gaming for the design of agents. Subsequently, Section 4.5 discusses the validity of our proposed data extraction tool. Finally, in Section 4.6 the conclusions of this chapter are provided and the second research question of this thesis is answered.

4.1 Comparing the design processes of agent-based modelling and gaming

To examine how gaming can support the design of an agent-based model, it is useful to analyse the design processes of both methods on meta-level. Nikolic and Ghorbani (2011) and Duke and Geurts (2004) provide frameworks for developing agent-based models and games, respectively. An elaboration on these frameworks can be found in Appendix A.

From this can be concluded that the design processes of both methods corresponds to a large extent. Four similar phases can be identified: 1) a problem identification phase, 2) a system analysis phase, 3) a model design phase, and 4) a model development phase. Each of these phases consist of several interconnected steps, which are, in practice, usually passed in an iterative way (Nikolic & Ghorbani, 2011; Peters & Van De Westelaken, 2011). In general, for each phase a main question can be formulated, related to the goal of that phase:

- *Problem identification phase:* What is the problem?
- *System analysis phase:* What does the system look like?
- *Model design phase:* How do we represent this system in a model?

- *Model development phase:* Did we build the model sufficiently well, given its purpose(s)?

4.2 Combining the design processes of agent-based modelling and gaming

Now the design processes of agent-based modelling and gaming are structured, we can explore how both methods can be combined. In 3.4 we have delineated the scope of this thesis and set some important principles that the combination must meet. We only consider combinations in which games are used to support the design of agent-based modelling. The starting point of our analysis is, thus, after agent-based modelling has been chosen as a method to analyse some socio-technical system. This implies that the problem identification phase already has been performed, otherwise this decision never could have been made. Therefore, it is assumed that, within this scope, games cannot contribute to the problem identification phase, since this is already finished.

Nevertheless, games can support the other three phases of the design process of an agent-based model. Figure 4.1 shows how the design frameworks are combined when games are used to support the system analysis phase (solid arrows), the model design phase (striped arrows) and the model development phase (dotted arrows). Notice that the option of supporting the model design phase consists of two different paths: by using a newly designed game, or by using an existing game as basis for a new game. All these possible combinations will be elaborated in the next subsections.

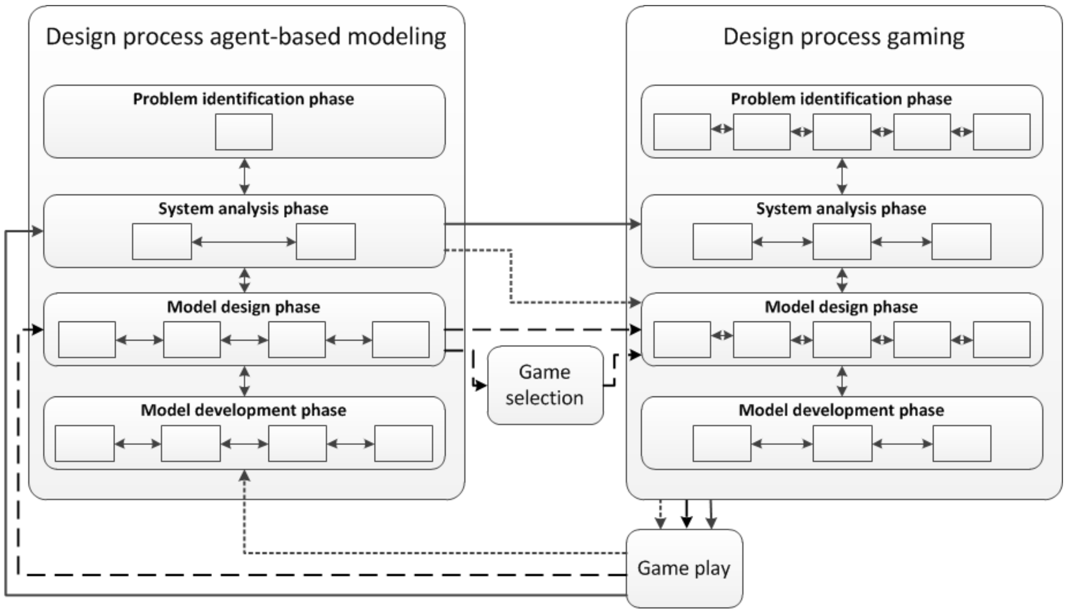

Figure 4.1: A combination of the design processes of agent-based modelling and gaming

4.2.1 A game to support the system analysis phase

The most important goal of the system analysis phase is to identify the internal structure of the system. This includes identifying the main actors and their behaviour, the relationships between those actors, a specification of the actions performed, and a description of the environment in which the actors are performing (Nikolic & Ghorbani, 2011). Traditionally, this is done by means of a literature study and interviews with domain experts. However, games can be used as additional method to fulfil this goal.

With this purpose in mind, a clear distinction can be made between two different categories of games. On the one hand there are games to extract information from relevant actors, without recreating the system. A game, then, functions as a means to stimulate creativity, or to increase commitment of the players. Although the topic of the game is similar to that of the reference system of the agent-based model, the game itself is no representation of the system. The rules and constraints mainly facilitate the game, e.g. increase competition, cooperation or creativity, but are no representations of real world institutions. Since games in this category do not share the same underlying conceptual model with agent-based models, we consider this category out of scope and will not further elaborate on them.

On the other hand, there is a category of games which are tailored to the specific context of the reference system. The game, then, is exploratory in nature and functions as an environment, which triggers players to come up with relevant aspects of the system, while playing the game, or during debriefing sessions (Lederman, 1992). This includes, for example, indicating whether all relevant actors are modelled, or whether the dynamics of the game sufficiently matches the dynamics of the reference system. This method can be regarded as a form of participatory modelling (see Section 3.4.1). Because the players need to be familiar with the reference system, the players should be the actual stakeholders. Furthermore, because the system analysis is not finished (yet), the simulated environment is per definition a less complete representation of the reality than desired. This implies that the in-game behaviour is no valid representation of the reference system (yet).

A game can never be the first step of the system analysis, since part of this analysis has to take place to identify some relevant aspects, e.g. the key actors (in order to formulate roles) and their interests (in order to formulate goals). The more traditional methods for performing a system analysis can be used to perform these first step(s). When a game is used to improve the system analysis in an early stage, it will be rather abstract.

4.2.2 A game to support the model design phase

In the model design phase, the system analysis is in an advanced stage: the main actors, their behaviour, relations and actions, and the environment are specified. Simple models, such as goal trees, causal models, and component matrices, can be used to graphically represent the relations within the system. The main goal of this phase is to 'translate' these real-world aspects into a computer model. Here, games can be used to simulate the system in order to generate data that are used to formalize and to quantify the relations of the model (i.e. to design rules). The specific purpose of the game, i.e. the operationalization of the variables in which one will try to gain insight, will follow from the model design phase of the agent-based model. This will concern those aspects, for which literature and participatory design do not provide sufficient clarity in how to implement them in a model. Here, games can be used to simulate the system in order to generate data that are used to formalize and to quantify the relations of the model (i.e. to design rules). The specific purpose of the game, i.e. the operationalization of the variables in which one will try to gain insight, will follow from the model design phase of the agent-based model. This will concern those aspects, for which literature and participatory design do not provide sufficient clarity in how to implement them in a model.

Because the agent-based model and the game are representations of the same system, the system analysis that has been made for the agent-based model can be used for the game as well. Based on this analysis all the standard steps of the game design process can be carried out. During this process, the goal of the game has to be kept in mind closely. Not only should the game become a valid representation of the reference system. Also, the variables of interest should be implemented in such a way that they can be monitored and processed. This implies that in case one is explicitly willing to measure an ill-defined concept (such as trust), one has to make important design choices concerning the formalization of this concept *before* the model design phase of the game. Otherwise it is not clear what exactly should be measured.

When these design choices have been made, the next question is whether to design a new game from scratch or to use an existing game as a basis for a new game. When a game is designed from scratch, the main focus lies on *how* the reference system can or should be represented in the game, in such a way that it is valid. A new design, obviously, goes along with a lot of freedom. It provides the possibility to implement specific characteristics of the reference system into the game. Furthermore, the goal of the game, collecting data, can serve as a basis for the model design. Some variables will be hard to capture when they have not been made explicit in the game. A consequence of a newly designed game is that the testing phase of the game is relatively time consuming.

When an existing game is used as a basis for a game, the first focus lies on the *selection* of a suitable game. Such a selection has three phases: surveying existing games to identify ones possibly suitable for adaptation, investigating in detail the suitability of the games selected for consideration, and modifying the chosen game to fit the purposes of the game (Stahl, 1988). An advantage of using an existing game over designing a whole new game is that it can save a lot of time and cost, since the design process can be partially skipped. However, the selection process of a suitable game can be a time intensive task as well. Sources in which games are described are very diverse and scattered. Furthermore, it is from these descriptions not always clear, what the exact goals, roles, rules and constraints, but also the structure, artefacts, and processes are. However, a detailed insight is important to determine whether a game is suitable or not to fit the purpose. Stahl (1988) argues that it is required to play a game for at least a couple of runs to get an adequate understanding of it. The speed of the selection process, thus, depends for a large part on the experience of the designer. Given the dynamic and evolving character of socio-technical systems and the specificity of model's scope, it is assumed that an existing game never is perfectly fitting to function as a data collection tool for the reference system. Therefore, after a game is chosen as a basis for a new game, it requires some modifications in order to match the goal and reference system. Whether this is an extensive process fully depends on the number and the type of modifications that are made. Also the duration of the testing phase is directly related to these modifications. When slight modifications are made (e.g. some points in the game are appointed on which data are measured) this will not require much additional time. However, when the nature of the game is modified, e.g. because some system elements from the reference system are added, the modification and testing of the game will take far longer.

4.2.3 A game to support the model development phase

Games can also be used to support the model development phase. During this phase the actual model of the reference system is build, and the most important question is, whether this is done sufficiently well. Hereby, verification and validation of the model are crucial steps. In order to support this phase, games can, in particular, be used to improve the validation of an agent-based model. In Section 2.3 already is explained that the validation process of agent-based modelling is a difficult task, because the model data cannot be compared with the reference system, since this system does not exist yet. One method to validate is by model replication, whereby a second model of the reference system is build. This second model can have the form of a game. A comparison between the simulation outcomes of both methods can be a source of validation (Nikolic et al., forthcoming). Based on these outcomes, the formalization and the actual model can be improved to achieve better results.

4.3 Gaming as a data collection tool for agent-based modelling

In the previous section, we discussed several possibilities how gaming can support agent design. These applications may provide useful contributions to more realistic agents. Given our goal to make agents behave more realistically, we choose to focus on the application whereby gaming supports the model design phase of agent-based models, since we expect that this option will contribute the most to our goal. The gap between global knowledge about how agents behave and the implementation of precise rules in models is wide. In cases where games can function as a valid data collection tool, rules can be based on the extracted data, which is very helpful in overcoming some of the design and formalization problems of agents. Little research has been done on this topic. The basic idea of the method is simple: analyse a (part of a) system, replicate it in a game, play the game and observe the players, collect data from the game, and translate this data to rules for agents. However, as we will see in the remainder of this thesis, there are many snags in these steps. In order to assess these, it is important to elaborate on the exact requirements of the 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 lies 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" (Ostrom, Gardner & Walker, 1994).

The four layer model of Williamson (1998) 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 (Groenewegen, 2005; Groenewegen & Koppenjan, 2005). It is not within the scope of this thesis, to go into detail on these topics (for an elaboration see, e.g. Ghorbani, Ligtvoet, Nikolic & Dijkema, 2010; Groenewegen & Koppenjan, 2005; Williamson, 1998). The identification of different institutional levels is sufficient 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 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 4.2

4.4 Using games to collect data or not

An important step in the design process of agents is the decision whether or not to use gaming as a data collection tool. This decision must hinge on the answer to the question, whether gaming can be a useful device for supporting the model design of agents. This means that the model must have at least one type of agent that represents an actor from the reference system, for which there are difficulties with the modelling of sufficiently realistic behaviour. This implies that the incorrect modelling of the agent may lead to a disturbance of the model as a whole. It is hard to make statements about situations in which those difficulties emerge, since there are examples in which the modelling of relatively simple aspects of behaviour is a real challenge, and the modelling of complex behaviour is a relatively easy task. In general, the number of causal relations, within and between agents, is a good indicator for how difficult the modelling process is. Furthermore, before the method is applied, there must be decent reasons to believe that gaming can contribute to these design problems. Thereby the limitations and trade-offs, that are discussed in this chapter and the next, should be taken into account. Based on work of, among others De Caluwé, Geurts, Buys and Stoppelenburg (1996), Van De Westelaken and Peters (2011) mention several other pragmatical conditions for applying a game. These include not too much time pressure, using participants that are not ‘tired of games’, and a suitable climate for games (i.e. no hidden agendas or conflicts). Stahl (1988) points out that, besides the costs and benefits of the game, also

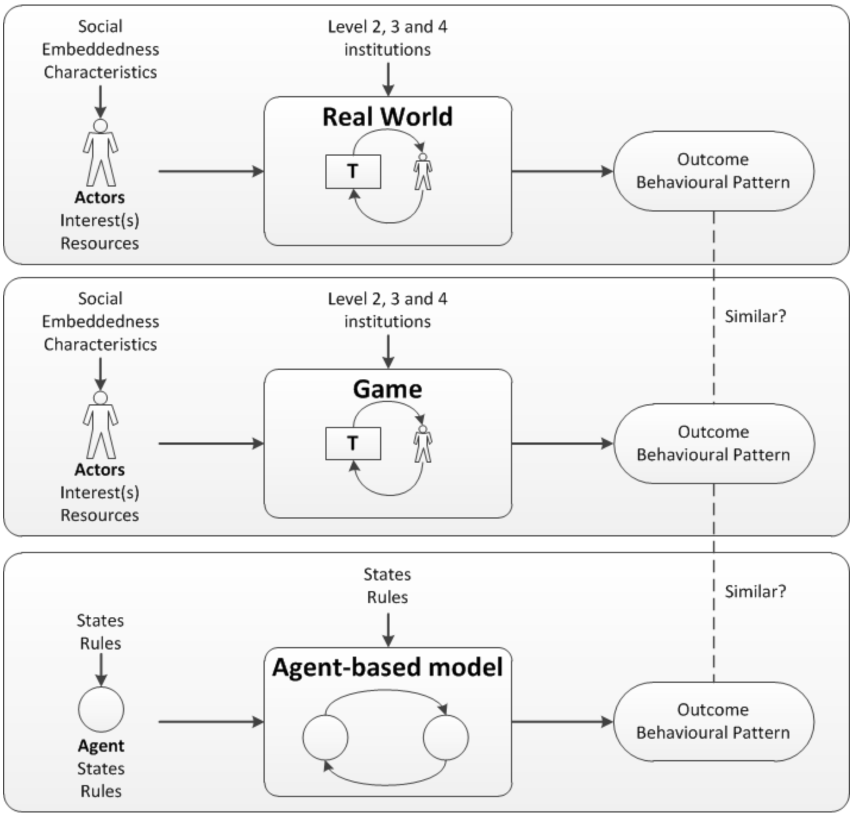

Figure 4.2: Schematic overview of the aspects that shape behaviour in the real world, in a game, and in an agent-based model

other considerations determine whether a game is used or not. These include questions like: Do we already have experience in gaming? Has the experience been successful? Is gaming an area in which we want to build competence over the long run? (p. 138).

In case the proposed method seems usable, there should be considered whether it is *sufficiently* useful, i.e. whether the benefits outweigh the costs. The costs of the method can be subdivided into three main categories. The development costs include all costs that are required to design and build the game. One can think of salary for the designer(s), costs of required resources, and copyright costs in case existing games are used as a basis for the new game. The operational costs of the game include all the costs that are required in order to play the game, e.g. salary for the game leader, rent for hiring an online server, and costs related to motivating people to play the game (promotion, financial compensation, etc.). Also costs related to data collection, e.g. cameras to record the participants, and salary for observers and interviewers (see Section 6.1), fall within this category. The last category that can be identified are the costs related to data analysis. This includes costs related to processing raw data into useful and insightful information. It is out of scope to further elaborate on these costs. However, it is recommended that further research is done to identify the costs of game design more precisely. This facilitates a quick and solid estimation that can be made on beforehand, in order to estimate whether the method is feasible or not, in a specific situation.

The benefits of the proposed method are reflected in the quality of (the rules of) an agent-based model. Since our aim is to use a game to generate information about the reference system on which these rules can be based, the quality of this information can be considered as an indicator for the benefits of the method. This includes, for example, the accuracy and the level of detail of this information about the reference system.

The benefits of the method depend on the quality of the information that is retrieved by means of the game, and the information that is already available. The higher the quality of the information available (or retrievable via other, more traditional methods), the higher the quality of the information retrieved from a game needs to be, in order to result in a significant contribution to the design of an agent-based model. There is no objective threshold for this quality, since it depends on the purpose of the agent-based model. These two aspects, the quality of information and the relativity of the requirements, are covered by the validity of the game. Therefore, this can be considered as the main criterion for the benefits. In the next section, there will be elaborated on this validity.

4.5 The validity of the data extraction tool

When a game is used as a data collection tool that supports the design of rules for agents in agent-based models, it is required that this tool is valid. In general, validity refers to the extent to which a model measures what it claims to measure. It concerns the question whether a model is an accurate representation of the real-world system, from the perspective of the intended uses (Sargent, 1998). However, it is not clear from this description what exactly is understood by an accurate representation. It remains unclear, for example, whether games based on a metaphor are valid (cf. Peters, Vissers & Heijne, 1998). Therefore, we follow a more utilitarian definition provided by Raser (1969), with respect to the use of gaming in research: "a model can said to be valid to the extent that investigation of that model provides the same outcomes as would investigation in the reference system" (cited in Peters et al., 1998, p. 23). In our case, then, a game can be considered as a valid data extraction tool for human behaviour, in case it 'triggers' realistic behaviour (i.e. the same behaviour as in the reference system would occur), and this behaviour is captured.

Raser (1969) suggests four criteria for the validity of gaming as research tool. The first criterion is *psychological reality* which is the degree that a game provides an environment that seems realistic to the players. An unrealistic environment may cause players to show different behaviour than they would do in real-life situations, for example, make more risky decisions. The second criterion is *structural validity* which is the degree "that its [a game's] structure (the theory and assumptions on which it is built) can be shown to be isomorphic to that of the reference system" (Raser, 1969, p. 144). Game elements should be congruent to the reference system, but do not necessarily have to be similar. The third criterion, *process validity*, concerns the congruency between the processes between a game and a reference system. It is defined as the degree "that the processes observed in the game are isomorphic to those observed in the reference system" (Raser, 1969, p. 144). Examples include interactions and negotiations between actors, and flows of information or resources (Peters et al., 1998). The last criterion is *predictive validity* which is "the degree that it [a game] can reproduce historical outcomes, or predict the future" (Raser, 1969, p. 144). This can be assessed by comparing game results with (known parts of) the reference system. Within our aim, the outcomes, mentioned in the last criterion, refer to the extent of realism of the behaviour, not to the end states of the game. Therefore, the predictive validity can be considered as a result of the psychological reality, the structural validity, and the process validity, and can function as a general indicator of the validity of the game.

In the remainder of this thesis, several aspects will be discussed that (may) affect the validity of our proposed tool. The three underlying criteria mentioned above will be used to test, if, and how, the general validity will be affected by the design choices a modeller makes when using a game as a data collection tool.

4.6 Conclusion

From this chapter, we can draw the following conclusions:

- The design processes of agent-based modelling and gaming correspond to a large extent. Four similar phases can be identified:
  - a problem identification phase
  - a system analysis phase
  - a model design phase
  - a model development phase.
- Gaming can contribute to the definition of realistic behavioural rules for agents in three ways:
  - **Support the system analysis phase**. Games help to identify the internal structure of the system. This includes identifying the main actors and their behaviour, the relationships between those actors, a specification of the actions performed and a description of the environment in which the actors are performing. A well performed and complete system analysis forms the basis of realistic rules.
  - **Support the model design phase**. Games can be used to simulate the reference system in order to generate data that are used to formalize and to quantify the relations of the model (i.e. to design rules).
  - **Support the model development**. Games can function as a way to validate the agent-based model by means of model replication.
- When games are applied to support the model design phase, one must:
  - be able to generate valid, i.e. sufficiently realistic, behaviour taking into account:
    - the ability to replicate behaviour from the reference system
    - the replication of the reference system in a game, by means of roles, goals, rules, constraints, and resources
    - suitable players for the game.
  - be able to measure the desired data.
  - be able to analyse the data.

Chapter 5

Design choices games

In the previous chapter we proposed to use a game as a tool, to extract information about (human) behaviour, in order to support the definition of realistic rules for agent-based models. In the remainder of this thesis, we will refer to this as 'using a game as a data collection tool'. Furthermore, in the previous chapter we identified three basic requirements that must be met, in order to use a game as a data collection tool: one must be able to generate valid data, be able to measure the desired data, and be able to analyse the data. Many aspects of the design process influence whether, and to what extent these requirements have been fulfilled. Given the scope of this thesis, we will not elaborate on the design process of the game itself. Excellent elaborations about this process can be found in, e.g. Duke and Geurts (2004), and Salen and Zimmerman (2004).

However, several aspects can be identified that explicitly affect the validity and the feasibility of the proposed data collection tool. This chapter will elaborate on those aspects that relate to the generation of valid behaviour by means of a game (i.e. game design), and discusses trade-offs that have to be made in order to come to a solid design. Section 5.1 discusses those aspects that are important concerning the question which players one should use in the game, to come to suitable rules. Section 5.2 discusses the aspects concerning the replication of the reference system. In Section 5.3 several aspects are discussed concerning the types of behaviour that may occur in the reference system, and thus, the game should evoke. Finally, in Section 5.4 the conclusions of this chapter are provided.

5.1 Players of the game

In this section, we discuss two important aspects concerning the suitability of players for our data collection tool. Section 5.1.1 elaborates on the use of selection criteria for players. Section 5.1.2 discusses the importance of sufficiently motivated players.

5.1.1 Selection criteria for players

In Section 4.3 we have seen that the behaviour of players is shaped by a combination of the social embeddedness in the system they come from, their characteristics, their goals and their resources. Ideally, a gaming simulation is played with the actual stakeholders from the reference system. In this case, the characteristics and the social embeddedness that shape the players' behaviour match with reality and there is no concern that this may lead to invalid behaviour. This contributes to the psychological reality of the game. Furthermore, the stakeholders often have a lot of implicit knowledge about their roles, which can lead to a positive difference in nuance compared to (simplified) role descriptions. This aspect has a positive influence on the process validity.

Playing with the actual stakeholders has also a major downside. Generally, the number of potential participants is much lower. There are actors within socio-technical systems where the potential number of players is no problem at all e.g. consumers of utility goods, or rail passengers, but the majority of the actors will have a far more limited number of potential players, e.g. a specific authority, or an energy company. A reduced number of participants decreases the amount of data collected, which may have a significant effect on the statistics that can be applied (see Section 6.2). A simple solution to insufficient stakeholders is playing the game with players, other than the actual stakeholders. However, this implies that the characteristics and the social embeddedness of the players is not controlled on beforehand. Different characteristics and norms may have significant effect on the behaviour. An experienced businessman, for example, will enter a negotiation in a whole different way, compared with an inexperienced student. Therefore, it is important to control these aspects by means of selection criteria (e.g. age, profession, level education, culture etc.). Furthermore, De Caluwé et al. (1996) ask themselves whether gaming simulations can be used on all types of personalities. They assume this is not the case, but there has been done little research on this topic (derived from Van De Westelaken & Peters, 2011).

5.1.2 Motivation for game-play

Another aspect that influences the validity of the data collection tool is the reason why people become participants of a game. There has to be a driver that motivates people to actually play the game. These drivers can either be external or internal, based on both positive and negative reinforcers. These differences may influence the behaviour shown during the game. We assume that valid data are most likely to be derived from intrinsically motivated participants. This can be the case when people think the game is fun to play (c.f. the *ESP game*) or because they are happy to contribute to science (c.f. *Foldit* or *The Restaurant Game*). It is likely that some people will still misbehave during these games, but when the sample size is sufficiently large, this will wash away statistically when it is compared to typical behaviour (Orkin & Roy, 2007). Hereby, the game designer has to take into account that the 'fun factor' does not interfere too much with the psychological reality of the game. When a player can get high-scores, for example by behaving very unrealistically, this may significantly distort the data.

When people are obliged to take part in the game, e.g. students as part of a course, or employees as part of a training day, the fun factor is less important since this is not the driver that has to persuade people to play the game. However, this fun factor remains important, in order to motivate people to behave realistically and to keep them focussed. Boredom and frustration are invitations to misbehaviour and, therefore, can have a distorting effect on the data. The longer the duration of the game, the greater the risk on these emotions, thus, the more attention should be paid to this aspect.

5.2 Replication of the reference system

When using a game as a data extraction tool, a next requirement is to replicate the reference system into a game. In this process, several aspects may influence the validity of the tool. This section elaborates on three of those aspects. Section 5.2.1 discusses the consequences of a holistic or partial design. Section 5.2.2 elaborates on the level of abstraction of the game. Finally, in Section 5.2.3 design choices concerning rules and constraints are discussed.

5.2.1 Holistic or partial game design

One of the most important design questions concerns the scope of the game. The game can be a representation of a part of the system that is modelled in the agent-based model, or it can be a representation of the system as a whole. Also, the reference system of the agent-based model can be extended before it is translated into a game, to make it, for example, more enjoyable to play. The main advantage of a holistic design is that it offers the possibility to take all interaction effects into account. Furthermore, the more complete the context of the reference systems is represented, the more likely that it triggers the desired behaviour, since we are interested in the type of behaviour for that specific context. Both aspects contribute to a higher process validity, as well as to a higher structural validity.

There are also reasons not to strive for a holistic design. One reason is that certain systems, or artefacts, may not be suitable to be validly represented in a game. Also, a holistic system representation may cause a game to become very complicated to play, which increases the duration of the game and decreases the number of participants. Another important reason is that, generally, the more elements are included in a game, the larger the development time and costs. Because the number of potential causal relations increases exponentially per additional artefact, it seems reasonable to assume that the development time and cost will display a similar distribution. This can be an appropriate reason to replicate the reference system of an agent-based model into three smaller games instead of one big game.

A holistic design also includes the simulation of all relevant actors. As we have seen, this can be done by simulating them by means of roles, which can either be played by 'random' players or by actual stakeholders. The most ideal situation is that the game is played with all stakeholders at the same time, since this provides the most realistic context, and thus increases the psychological realism. In theory, this is very well possible, but in practice, as the number of actors increases, it becomes more unlikely that this actually succeeds. Besides from pragmatical reasons (planning, etc.), it will be hard to get everyone's willingness to join the game, since there is often nothing to gain for these stakeholders (as they are not necessarily the clients that requested the model).

Furthermore, critical actors of socio-technical systems do not necessarily play a large role in terms of effort, e.g. actors that act on very limited occasions or do simple, little time consuming tasks. When these actors are represented as roles in a game, the danger exists that this leads to very unbalanced games, which are boring for the players fulfilling these roles. It is possible to represent the absent actor(s) in some other way and play the game with the stakeholder(s) that are present. This, then, does require a valid representation of the absent actors(s), which, as we can understand from the topic of this thesis, can be quite a challenge and immediately raises questions concerning the validity. There are situations, however, where this representation is very well possible. For example, the granting of an authorization can be easily represented by (chance) cards, or by a decision made by the game leader, based on predetermined guidelines.

5.2.2 Abstract or detailed games

Another design choice that has to be made is the level of abstraction of the game. This dimension relates to the level of detail in which the reference system is simulated. The more abstract a game is, the more general the conclusions are, but, however, the more questions it raises towards the specific applicability. Recall the distinction we have made in Section 2.3.1 between analytical and design oriented science. A sufficiently detailed context may be particularly important when the game is played with the actual stakeholders, in order to let them reach a certain mindset (i.e. they should recognize the environment), so that the maximum benefit is derived from the fact that they, as actual stakeholders, know their role best.

5.2.3 Rules and constraints

The rules and constraints of the game define how the game is played, by determining what is allowed, what is forbidden and what is (im)possible. Section 3.2 discussed the concepts of rigid-rule games and free-form games (Stahl, 1988). Choosing between these two forms, has some important consequences on behaviour. When a rigid-rule game is used, the designer assumes that he knows all possible outcomes. The assumption is, that one knows how the world *might* work, only one does not know how the world *does* work. The focus of the game, in terms of data collection, lies on the retrieval of the distribution between those outcomes. Free-form games are much more flexible, because players have the ability to invent some of the rules as the game goes on. This leads to games in which the processes and the outcomes, are much more diverse, and possibly realistic, since the players are less bounded by the rules (at least, by the rules that are established in advance). This, however, leads to a game that is harder to monitor because of this freedom. A clear trade-off, thus, emerges between flexibility (and realism) on the one hand, and the ease/ability to monitor on the other hand. Notice that, in order to generate valid behaviour, the focus of rigid-rule games should be the rules of the game, while free-form games should be more focussed on the roles and goals of the players. This implies that there is an advantage when free-form games are played by the actual stakeholders, because these can fill in these roles in a more realistic way.

It is hard to make general statements about the rules, since rules may vary in nature, complexity, development time, etcetera. However, generally, the larger, and the more detailed the reference system is, the more rules are required, and the more complicated the game is for players to understand. Stahl (1988, p. 135) adds that "the more formalized a game, the more likely it is that the game will be more expensive to develop - but not necessarily to use". Thus, a trade-off emerges between the size and the level of detail of the game on the one hand, and the costs and complicatedness of the game on the other hand.

Furthermore, we want to elaborate on the extent to which rules have to match the institutions of the real world. This depends to a large extent on the context in which it is done. However, the presence of one rule can fundamentally change the dynamics of the game as a whole (Harteveld, 2011). For example, players may show completely different behaviour and follow different strategies when a game includes the possibility to die, to go broke, or to permanently leave the game in some other way, compared with games where this is not the case. This implies that the presence of one deviant rule compared to the reference system, may lead to significantly different, and possibly invalid, behaviour. Therefore, when rules are added or changed compared to the reference system, a game must be extensively tested and validated before it can be used as a data extraction tool.

5.3 Replication of the system behaviour

The previous sections discussed several aspects concerning the players and the replication of the reference system. The design choices concerning these topics do not only depend on the issues discussed, but also on the characteristics of the behaviour that one intends to simulate. Different types of behaviour, require different approaches in order to simulate them in a valid manner. This section elaborates on this topic. In Section 5.3.1 the difference between reasoned and habitual behaviour is explained, and we elaborate on the consequences for the game-design. Section 5.3.2 elaborates on normative behaviour.

5.3.1 Habitual decision making

There are many theories that aim to explain and predict the initiation of human behaviour, e.g. the *theory of planned behaviour* (Ajzen, 1991; Fishbein & Ajzen, 1975). According to this theory, which emphasizes the deliberate character of decisions, behaviour is predicted by the attitude toward the behaviour, the subjective norms and the perceived behavioural control.

However, decision making is not always a conscious and reasoned process. The majority of people's actions are based on routines and habits, which enables us to perform tasks without attention. Performing certain tasks subconsciously is necessary to save enough cognitive capacity for decisions that do require our full attention. Many research in different fields, has been done to the concept of habitual behaviour. Therefore, it is hard to give an unambiguous definition of a habit. The essence of most definitions is that habits are stable patterns of behaviour resulting from biological and social processes (Aarts, 2009). In general, two different levels can be identified on which habits are acquired: stimulus-response learning and goal-directed learning. An elaboration on these two concepts can be found in Appendix C.

In this thesis we adhere the perspective of habits as a form of goal-directed automatic behaviour (Aarts & Dijksterhuis, 2000; Aarts, 2009), since this aligns more with the level of detail and the complexity of the behaviour we are interested in. The main assumption of this approach is that actions are directed by underlying higher goals (Powers, 1973). The choice between multiple means to achieve a certain goal, starts with a reasoned selection of the alternatives. After repeatedly and consistently choosing the same alternative, both the sequence of behaviour *and* the choice itself will become automated (Aarts & Dijksterhuis, 2000). Thus, patterns of behaviour need to be 'activated' by actually performing the behaviour. Once this is the case, it will be, at least to some extent, automated behaviour.

An important question, then, is whether goal-directed behaviour is better predicted by either reasoned intentions, or by habits. The most common finding in research to this question is that both aspects are independent predictors for future behaviour (Aarts, 2009; Aarts, Verplanken & Van Knippenburg, 1998). Furthermore, an important finding is that habits and intentions interact in the prediction of behaviour. If someone has not developed a strong habit, intentions are a good predictor for future behaviour. However, when someone does have developed a habit, these intentions become less predictive and cease to guide future behaviour (Aarts et al., 1998). This phenomenon mainly occurs when the context in which the behaviour was performed, i.e. the time (e.g. time of day), the place (the physical location), and the situation (the circumstances, e.g. weather, other people, etc.), is stable (Danner, Aarts & Vries, 2008).

Simulating habitual behaviour in games Regarding the differences in nature of behaviour, we can identify three scenarios which can occur in the reference system: 1) decisions are made consciously and based on reason, 2) decisions are made, at least in part, subconsciously and based on habits , and 3) decisions are based on reason, but have the potential to become habitual behaviour. These scenarios all have other implications on the validity of the data extraction tool.

Reasoned behaviour In principle, it is very well possible to simulate reasoned decision making behaviour in a game. When our aim is to do so, the main goal of the game is to serve as a means to communicate the relevant criteria (upon which the decision will be based) to the player. A player, then, takes these criteria into account and makes an *in-game decision*. The main assumption is that, in case the game sketches the context of the reference system sufficiently well, i.e. when the psychological reality, the structural validity, and the process validity are sufficiently high, this behaviour will be a valid representation of the behaviour that would occur in reality. Thus, it is crucial to implement at least those criteria that function as predictor for the decision. However, implementing just those criteria does not necessarily mean the game is sufficiently detailed. Because the cognitive load differs when more or fewer potential criteria are implemented, the heuristics that the decision maker uses may also change. Because the cognitive load of (specific decision in) a game is expected to affects the outcome(s), it should be taken into account during the design process of reasoned behaviour.

Habitual behaviour When we want to simulate habitual behaviour in a game, we also need a player to behave as if he acts in the real world. However, in this case his own past behaviour in the reference system, will be the main predictor for the future behaviour. Thus, the goal of the game is to trigger this behaviour.

However, two related aspects of habitual behaviour make this a difficult task. On the one hand, habitual behaviour is mainly a subconscious process. This subconsciousness of habitual decision should be preserved during a game, because it is likely that people will behave differently when reason comes into play (that is, after all, the point of habitual behaviour, one stops reasoning and acts like he always acts). The players can not consciously make an effort to identify with a role or goal, but they *should* do so subconsciously. The trigger of this identifications, thus, fully depends on the realism of the context. However, a second aspect of habitual behaviour is that it is very context-dependent. This implies that the reference system should be modelled very precisely, and the game cannot just be a very abstract representation, in order to trigger habitual behaviour.

A fundamental question, then, raises whether it possible at all to simulate habitual behaviour in a game. It may be the case that games in general differ too much from reality, to trigger habitual behaviour. However, we assume that when games are sufficiently realistic, e.g. driving simulators, they are able to capture habitual behaviour. An interesting question, then, is whether there can be identified whether there is a certain degree to which a model must correspond in order to trigger habitual behaviour. However, as far as known to the author, there has no research been done on this subject.

Another risk emerges from the fact that games are per definition a simplified model of the reality, and thus have a reduced cognitive load. This may cause decisions to become more manageable, leading to more (unwanted) reasoned behaviour. Also the explicitness of decision and behaviour may lead to more reasoned behaviour. There is a high probability that players will make decisions more consciously because they play a game. This can be increased by confronting them with their own behaviour, either directly or indirectly, e.g. by observing them, or ask them about their motivations.

Modelling habitual behaviour has another crucial implication. Since we aim to trigger real-life behaviour, the game-player must actually display this behaviour in real-life. Therefore, game-players cannot be random players, but must be the actual actors from the reference system. This may significantly limit the number of potential game players.

Potentially habitual behaviour The third scenario that can occur concerns behaviour that is not yet habitual, but has a good possibility to become so, given a high frequency and a stable context in which the behaviour is displayed. This could be the case, for example, when actors function in a new environment, and have not developed habits yet, or when the system does not yet exist. This is the most problematic behaviour to simulate, because technically we need to trigger behaviour that does not exist yet. This implies that we need to create habitual behaviour my means of a game. This is a problem for two reasons. Firstly, as explained above, games have a reduced cognitive load compared to reality. When this leads to habitual behaviour (because the cognitive load is still too large to manage), the habits will be based on a simplified system. Also, the dynamics of the game, which does not necessarily be the same as the dynamics in the reference system, can influence the nature of the habits. The habits that are created, thus, are not necessarily the intended habits. Given the nature of this problem, this cannot be validated. Secondly, the habits have to be created in a very brief period of time, namely during game-play. Therefore, the duration of the game has to be sufficiently long. However, follow-up research has to be done, to find out the minimum duration of the game. Furthermore, it is not known whether these quickly learned habits are comparable with habits that are learned in the reference systems on a larger time-scale. This, also, requires further research.

5.3.2 Normative behaviour

Another relevant aspect that possibly influences behaviour are social norms. These can be defined as "the social or explicit rules a group has for the acceptable behaviors, values, and beliefs of its members" (Aronson, Wilson & Akert, 2005, p. 250). Research has indicated that witnessing the actions of others can have a powerful effect on (decision making) behaviour (Cialdini, Reno & Kallgren, 1990; Cialdini & Goldstein, 2004). Also, written information can cause people to behave according to the communicated norm (Parks, Sanna & Berel, 2001). The effect of norms on behaviour can occur subconsciously and may be underestimated by the individual (Nolan, Schultz, Cialdini, Goldstein & Griskevicius, 2008).

Norms are rather stable, but do change as result of, for example technological developments, interchanging cultures or specific incidents (e.g. terrorist attacks). Furthermore, norms may differ significantly between different social groups, such as cultures, religions, and political convictions. Because of these characteristics it is very hard to make generalizations about norms. However, it is clear that the extent to which norms do influence actual behaviour depends strongly on the 'salience', i.e. the extent to which the norm is visible and noticeable to the environment (Cialdini et al., 1990).

Representing norms in games As we have mentioned in Section 4.3, norms are part of the social embeddedness. They implicitly influence the outcomes of games via the players, whose behaviour is shaped by, among others, the norms from their own environment. When these norms are similar to the intended norms of the reference system, the effect on the behaviour should be taken into account in a valid manner. Norms are per definition similar when the players are stakeholders from the reference system. However, this is no absolute requirement. If players are not the actual stakeholders, it should be checked whether the norms do not deviate too much from the norms of the reference system. When individuals have significantly deviant norms, they are not really suited to function as players. In theory maintaining the correct norms can be part of their roles. However, given the embeddedness of norms and the fact that their effect on behaviour is (partly) a subconscious process, it is assumed that this will never lead to (valid) realistic behaviour.

Although it is possible to take norms implicitly into account, it is challenging to gain explicit insight in them. We have seen that the effect of norms on behaviour can either be a conscious or a subconscious process. When this entails a subconscious process, the players cannot be asked to give an indication about the effect. When, on the other hand, the effect of norms on behaviour entails a conscious process, the possibility exists to explicitly ask players about their normative motives. However, the danger, then, exists that this effect is underestimated (Nolan et al., 2008).

Representing changing norms in games In the previous paragraph, we have seen that norms, under the right circumstances, can be represented in games. The next step is to examine whether it is possible to represent norm changes. Norm changes can be bidirectional: the system may cause changes on the (implicit) norms of the players, and changing norms may result in a different behaviour. Both will be discussed.

In general, norm changes are a gradual process over a long time-span (with a few exemptions, such as a sudden change of mind after a terrorist attack). Because norms are deeply embedded in our being, they do not change from one moment to the other. Therefore, we assume that it is not possible to significantly change the norms of a player in one single game session. The time-scale of socio-technical systems, however, is very large. While the systems evolves, norms may change. An example includes the emission of carbon dioxide. The last decades, within the energy sector, norms concerning this emission have significantly changed from insignificant to influential (but to what extent?) after became clear carbon dioxide was related to global climate change. When a socio-technical system is influenced by such norms, we want to represent these into our modelling methods. In theory, a changing norm can easily be implemented into a game (e.g. as part of a role) via instructions. The question, then, is whether this norms will lead to sufficiently realistic behaviour?

Although players have the cognitive ability to react on those changing norms (based on an estimation or their imagination), it is highly unlikely that these norms will ever be a valid representation of the reality. As mentioned, norms affect behaviour consciously and subconsciously. As explained above, we assume it is unlikely that the subconscious 'part' of norms change within one game sessions. This implies that this part will remain to have effect during the game. The conscious 'part' of norms can be influenced. However, because it is very hard to picture the specific effect of norm changes because they are likely to be over- or underestimated. Therefore, we suggest not to assume that gradual norm changes in a game are valid predictors for behaviour. However, norm changes can be used to trigger changes in reactions. Picture the in-game message "Researchers found out that carbon dioxide is related to climate change with disastrous consequences for the world" in an investment game concerning energy. After this message players are more likely to change their strategy, e.g. by starting to invest in renewable energy. In this way, norm changes can facilitate games by invoking certain scenarios.

Although detailed research has not been done on this topic, it is expected that the conclusions concerning normative behaviour can be applied to all social embedded aspects that influence behaviour (e.g. culture, customs, values). The same line of reasoning can be applied to these aspects. When players already have those aspects embedded, they are taken into account implicitly. However, due to the same embeddedness, and their (partly)subconscious character, adopting different, or picturing changing social embedded aspects, will not lead to sufficiently realistic behaviour.

5.4 Conclusion

Within the context of game design, there are several aspects that explicitly affect the validity and the feasibility of the proposed data collection tool:

The choice of players should be such that they have a social embeddedness that is similar to that of those in the reference system.

- There is a trade-off between the strictness of selection criteria for players and social embeddedness.
- There is a trade-off between the strictness of selection criteria for players and the number of potential players.
- The most strict selection criterion is playing exclusively with actual stakeholders. This guarantees full validity with respect to social embeddedness, but reduces the number of potential players.

Players must be motivated to play the game.

- There must be a motivation for people to actually start playing the game.
- The ‘fun factor’ may interfere with the aim to simulate realistic behaviour.
- Players must remain motivated during the game play to avoid unrealistic behaviour.

The simulated system should be such that the player’s behaviour that is triggered is similar to that of those in the reference system.

- Design choices must be made concerning the **scope** of the model:
  - The game can be a representation of the reference system as a whole. This
    * provides the possibility to take all actors into account
    * provides the possibility to take all interaction effects into account
    * increases the likelihood to trigger realistic behaviour.
  - The game can be a representation of a part of the reference system. This
    * may reduce the complicatedness and duration of the game
    * lowers the development costs and time
    * may be done, when game artefacts are not suited to be validly represented in a game.
  - Representing more actors in a game, decreases the probability playing with all actual stakeholders.
  - The game should be in balance, with regard to roles of players. Too insignificant roles may lead to invalid behaviour.
- Design choices must be made concerning the **level of abstraction** of the model:
  - A high level of abstraction of the game raises the generalizability of the conclusions.
  - A high level of detail may be required to trigger valid behaviour.
- Design choices must be made concerning the **rules and constraints** of the model:

  - The game can be free-form, which
    * results in an unlimited diversity of outcomes
    * offers the possibility for more realistic behaviour.
  - The game can be rigid-ruled, which
    * leads to a more structured game
    * offers the possibility to assess all possible outcomes on beforehand.
  - The scope of the model is related to the amount of rules.
  - One single rule may cause the whole game dynamics to change.

In order to generate valid data with the data collection tool, it must be possible to simulate the behaviour of the reference system in a game:

There is a fundamental distinction between reasoned behaviour and habitual behaviour.

- Reasoned behaviour can be simulated by means of a game.
  - The game must trigger the same reasoning as would occur in the reference system.
- Habitual behaviour that already has been developed can be simulated by means of a game, under specific conditions:
  - The game must trigger the same behaviour as would occur in the reference system, without the interference of reason.
  - Actual stakeholders from the reference system are required.
  - A relatively realistic representation of the reference system is required.
- Potential habitual behaviour that has not been developed yet, cannot be simulated by means of a game.

Social norms do influence behaviour both consciously, and subconsciously.

- Stable norms can be validly represented, under a specific condition:
  - It is required that players already have those norms embedded before playing.
- Changing norms cannot be represented.
- It is expected that this conclusion applies to all social embedded aspects that influence behaviour.

Chapter 6

Design choices data collection and data analysis

In Chapter 4 we proposed to use a game as a data collection tool to support the design of agent-based models. In order to do this, it is not only required to simulate valid (i.e. sufficiently realistic) behaviour. Also it is required that this behaviour is measured, and that the generated data can be analysed. This chapter elaborates on these two aspects.

It is not the purpose of this chapter to give an exhaustive overview of all possible tools and methods, nor to provide an extensive description of them. This falls out of the scope of this work, and, moreover, dozens of books already have been written about this (e.g. Cohen, Manion & Morrison, 2007; Field, 2009; Shaughnessy, Zechmeister & Zechmeister, 2012). However, design choices with regard to data collection and data analysis may affect the validity and the cost of the data collection tool. The most important of them are discussed in this chapter. Section 6.1 discusses the most commonly used data collection methods. Section 6.2 elaborates on data analysis. The most important aspects and conclusions are summarized in Section 6.3.

6.1 Data collection methods

The basic principle of data collection is very intuitive to understand. One examines what is going on (i.e. how a specified variable changes) in a certain system, e.g. the reference system or a game, and administrates this. Two main methods for data collection are observational research, in which an observer examines what happens in the system, and survey research, in which participants are asked to the variables of interest. Although this sounds as a simple and straightforward task, data collection must be a well organized, sophisticated process in order to generate valid data.

In this section we discuss the three most common methods for data collection. In Section 6.1.1 observational research is discussed. In Section 6.1.2 and Section 6.1.3 the most common forms of survey research are discussed, which are questionnaires and interviews, respectively.

6.1.1 Observational research

The distinctive feature of observation as a research process is that it offers the opportunity to gather 'live' data from social situations. Because the observer can directly look at what is taking place, instead of relying on second-hand accounts, this method has the potential to yield more valid or authentic data than would otherwise be the case with mediated or inferential methods (Cohen et al., 2007). This provides the possibility to do a reality check on the players' behaviour, to see whether they behave as they say they would do, and it also leaves room to classify evident abnormal or misbehaviour as such, in order to reduce its potential disturbing effect. Note that observation can be done directly, but also indirectly, e.g. by means of a video camera or audio recorders. Furthermore, observational research includes automated data collection of objective variables, such as log files of all amounts of resources of the players after each turn.

According to Morrison (1993) observations enable the researcher to gather data on four settings (adapted from Cohen et al., 2007, p. 397):

- the physical setting (e.g. the physical environment and its organization)
- the human setting (e.g. the organization of people, the characteristics and make up of the groups or individuals being observed, for instance, gender, class)
- the interactional setting (e.g. the interactions that are taking place, formal, informal, planned, unplanned, verbal, non-verbal etc.)
- the programme setting (e.g. the resources and their organization, pedagogic styles, curricula and their organization).

When we focus on the specific variables that are relevant for agent-based modelling, and consider the different categories of sources that can function as input condition for a rule (see Section 2.1.1), we see that observational research is not suitable for each category. Latent variables, per definition, cannot be directly observed. It is possible to observe non-latent states of players, and their behaviour. However, it is for observers hard to see, how these states are interpreted by the players, and which of those aspects play significant roles during decision making.

The types of observation lie on a continuum from unstructured to structured (Patton, 1990). In a highly structured observation, the observer needs to know in advance what he is looking for and has worked out observation categories on beforehand. A semi-structured observation will have an agenda of issues, but the data-collecting process will happen in a far less predetermined and structured manner. In an unstructured observation the observer does not really know what he or she is looking for. The less is known about the potential behaviour on beforehand, the more aspects may be relevant, and thus need to be monitored. This increases the cognitive load for observers. Furthermore, unstructured observations are more likely to be affected by the subjective interpretation of observers.

In summary, observational research has several requirements: there must either be an observer who analyses what happens, or there must be instruments that directly administer the relevant information. This may occur either directly, or indirectly. Furthermore, the variables that are analysed must be observable. This implies that latent variables cannot be measured via this way, and that ill defined variables need to be sufficiently operationalized. This also implies that the amount of variables and processes that are observed, must be manageable for the observer. The quality of the data depends on the subjective interpretation of the observer.

6.1.2 Questionnaires

Questionnaires are a form of survey research, which are used to examine people's thoughts, opinions and feelings. They are characterized by their use of a set of predetermined questions. Written, or computer-entered responses to these questions provide structured data, both numerical and non-numerical, that is often relatively straightforward to analyse (Shaughnessy et al., 2012). Downsides of questionnaires are a large development time, the possible unsophistication of the data that are collected and the limited flexibility of response (Cohen et al., 2007).

Like observational research, questionnaires can be subdivided on a continuum from structured to unstructured. In a completely open (unstructured) questionnaire a participant is invited to 'write what he wants'. On the other hand, in a completely structured questionnaire the freedom is limited to the filling of a box. Generally, closed questions are directly to the point and deliberately more focused compared to open questions. Furthermore, they are better to compare, quicker to code up, and better to analyse with statistical tools. Using closed questions may be accompanied by the risk that possible answers are not represented. Open questions are useful when the possible answers are unknown, or when there are many possible answers possible, which would result in a (too) long list of options. Furthermore, they are suitable for investigating complex issues, to which simple and structured answers are insufficient.

Questionnaires conducted by means of a computer have the advantage that the answers are automatically coded, reducing time and costs. When questionnaires are internet based, there is a risk for the selection bias, which is a systematic error in the data due to how participants are chosen. People who respond to our questionnaire(s), as part of playing an online game (for fun, or for research purposes) may differ in specific characteristics from those who do not play online games.

With questionnaires it is possible to examine all categories of sources that can function as input condition for a rule (see Section 2.1.1). However, questionnaires during the game may have a disturbing effect on the gameplay, e.g. it reduces the speed of the game or it distracts players. Also, filling in questionnaires may be perceived as a boring task by the players. Therefore, the number of items per questionnaire, and the number of questionnaires per game is limited. Furthermore, the more time elapses between an event and a question about this event, the higher the risk on an inaccurate answer to a question. This implies that questionnaires about specific events must be conducted during the game if it takes a long time (e.g. several hours) to play the game.

The quality of the data that are generated, depends on the players who fill in the questionnaires. An important aspect is the honesty of the players. However, this is hard to verify. Another aspect is that all players need to interpret the question in the same way. This may lead to problems when one wants to gain insight in ill-defined concepts, such as trust. When you ask several players: *Can you indicate on a scale from 1 to 100 how much you trust the other player(s)?*, it remains to be questioned whether you measure the same aspect, since everybody has got his own specific interpretation of trust. This can be solved by defining the concept more strictly, and use, for example, validated questionnaires to measure trust. However, these questionnaires consist of more items, resulting in longer, more time consuming questionnaires.

Taking all these issues into account, it becomes clear that a balance has to be found in the frequency and the size of the questionnaires. Thereby, the disturbing effect of questionnaires, the need to ask questions in time in order to get sufficiently accurate answers, and the specificity of the items should be taken into account. Furthermore, the less structured the items are, the more comprehensive an answer is allowed to be, but the more work it is to process the data.

6.1.3 Interviews

Another form of survey research is by means of interviewing participants by a professional interviewer or by the game leader. Interviews allow interviewees to discuss and elaborate on their interpretations of the world, and to express how they view situations from their perspective (Cohen et al., 2007). Basically, interviews are an oral variation to (written) questionnaires. This makes both methods very similar to each other. However, several characteristics require some elaboration.

The main advantage of interviews is the flexibility of the method. Researchers have a lot of control over how interviews are conducted. Also, during an interview, both the interviewee and the participant can ask for clarifications when questions and answers, respectively, are not clear. Furthermore, interviewers can anticipate on the provided answers and ask for elaborations or ask follow-up questions. The most significant disadvantage of the method are the costs, in both money and time. Furthermore, there is a potential for interview bias. This occurs when the interviewer is selective in recording the interviewees' answers or tries to adjust the wording of a question to fit the respondent (Shaughnessy et al., 2012). The best way to prevent this bias is to employ highly motivated interviewers, provide detailed instructions and monitor them closely.

Interviews can take place before, during and after the game. Because we are interested in actual behaviour, rather than intended behaviour, the focus should be on interviews during and after the game. Interviews during the game do not necessarily take a long time, but also include single questions such as *why did you do that?*, and *can you elaborate on your choice?*. These questions, like questionnaires, may have a disturbing effect on the game. In general, as the length of an interview, and the difficulty of the questions increases, the likelihood of a disturbing effect becomes larger.

The quality of the results of an interview strongly depend on the interviewee. As we have discussed in Section 2.3.1, there are several reasons why answers may be inaccurate, e.g. because the interviewee is biased or because of strategic reasons. A way to reduce, or even overcome these problems is to combine observational methods and interviews. This can be done by showing video's of the player's behaviour or discussing trace logs of players. In this way the quality of the interview increases, as the memory of the player is refreshed and he is confronted with his own actual behaviour. Also, the quality of the observations increases, because it becomes less dependent of the subjective interpretation of the observer, since the player can elaborate on it.

6.2 Methods for data analysis

Data anaysis is the process of inspecting and processing raw data in order to highlight useful information. Overall, data analysis can be categorized into qualitative and quantitative data analysis.

6.2.1 Qualitative data analysis

"Qualitative data analysis involves organizing, accounting for and explaining the data; in short, making sense of data in terms of the participants' definitions of the situation, noting patterns, themes, categories and regularities" (Cohen et al., 2007, p. 461). There is no single or correct way to analyse qualitative data. This is depends on whether the method chosen is fit for purpose. For an elaboration on qualitative research methods, data analysis and ongoing discussion concerning the field of research, we refer to e.g. (1999) Miles and Huberman. In this section, we will specifically discuss qualitative data collection from games.

Qualitative data analysis plays a crucial role when one aims to design rules. Based on qualitative methods, the structure of the rules can be determined. When a rule does not require quantitative symbols, this structure is a total rule in itself (e.g. the rule: *if* *product x is available, then buy product x*). In other cases the structure is required so that quantitative methods can effectively be applied. For example, consider a decision problem in which an actor has to choose between 3 alternatives based on a number of criteria. In order to predict the outcome, the used decision mechanism has to be known, so the correct variables can be measured, and the correct quantitative analysis can be performed. When the actor, for example, bases the decision on a satisficing mechanism, we have to find out the order in which the criteria are analysed and the thresholds for what is good enough or not. However, when the actor uses a multi criteria analysis, we have to find out the decision weights of each criterion, using other statistical methods.

The most common forms of qualitative data analysis in games, is by means of unstructured, in-depth interviews. Given the flexible nature of this method, data collection and data analysis basically take place simultaneously. Interviewers directly process the responses of the interviewees, in order to ask suitable follow-up questions. Additional steps of data-analysis are comparing (summaries of) interviews with each other, in order to find similarities and differences. Other methods include systematically comparing log-files of discussions, and analysing unstructured observations and qualitative questions of questionnaires. Generally, due to the unstructuredness of the data, analysing qualitative data is a time consuming activity. Furthermore, in some situations it can be very hard to determine whether there is a significant effect or pattern, or whether there is not. This problem can be overcome to encode qualitative data in order to perform quantitative analyses. The quality of this data and analyses, then, becomes strongly dependent of the (subjective) interpretation of the encoder.

6.2.2 Quantitative data analysis

With quantitative data analysis numerical data are analysed, by means of one of the many statistical applications. Which application can, or should be used, depends on several factors, e.g. the number of samples that have been taken, whether these samples are dependent or not, the sample size, and the scale of the data. A detailed overview of the most common statistical methods and their main assumptions and requirements can be found in, e.g. Field (2009). In the design process of rules, we are mainly focused on exploring the relations between variables. Therefore, the applications we are most likely to use are the Chi-squared test, t-test, correlation, and single or multiple regression.

One of our main concerns is whether the sample size is sufficiently large. The sample size is directly related to the probability of making a type I error (α), i.e. believing that there is an effect while in reality there is not, and the probability of making a type II error (β), i.e. believing that there is no effect, while in reality there is. The α-level is referred to as the significance level of a test. The β-level is usually mentioned in connection with the power of a statistical test (i.e. 1 - β).

An obvious trade-off exists between α and β. As the probability on a type I error decreases, the probability on a type II error increases. However, the exact nature of this relation is complicated and depends on several assumptions (Field, 2009). Standard levels for α and β are 0.05 and 0.2, respectively. Furthermore, the sample size is related to the effect size of the observed effect. The smaller the effect size, the larger the sample size should be, in order to find a statically significant relation. Table 6.1 provides an overview of required sample sizes to detect correlations, with different α's, β's and effect sizes[1]. In social sciences a correlation effect of 0.1 is considered as a small effect. Correlation effects of 0.3 and 0.5 are considered as medium and large effects, respectively (Field, 2009).

[1]The values of this table are determined with a statistical tool found on `http://www.stattools.net/SSizcorr_Tab.php`

r \ $\alpha(\beta)$	0.05 (0.8)	0.01 (0.8)	0.05 (0.9)	0.01 (0.9)
0.1	617	999	853	1296
0.3	67	107	92	138
0.5	23	36	31	46
0.7	11	16	14	20

Table 6.1: Required sample sizes for detecting correlation effects (r) with variable α and β.

With regard to regression analysis, there are no generally agreed methods for relating the sample size to the number of independent variables. Several suggestions for heuristics are provided, for example:

- Hair, Black, Bablin, Anderson and Tatham (1998) suggest that the minimum ratio of observation to variables is 5:1, but the preferred ratio is 15:1 or 20:1, which should increase to 50:1 when stepwise estimation is used.
- Good and Hardin (2009) suggest the rule of thumb $N = m^n$ where N is the sample size, n is the number of independent variables and m is the number of observations needed to reach the desired precision if the model only has one independent variable. This would imply that when sample size is 1000 and $m = 5$, the maximum number of independent variables this model can support is 4.

Although these sample sizes indicated by these heuristics vary to some extent, they provide a good indication for the order of magnitude. It is clear that the required sample size grows significantly as the number of independent variables increases.

Advanced statistics Although they can be very useful to gain insight in relations between variables, traditional statistics only can help us to some extent in analysing socio-technical systems. Most statistical applications require samples to be independent observations. Also they assume the strengths of relations to be time-independent (i.e. equal over time) (Chappin, 2011). However, most behaviour within socio-technical systems is path-dependent, and there is no ground for assuming that the strength of the relations is stable over time. It is conceivable that in some situations the costs of a product, for example, play a far more important role, than in other situations, because the context and the states of the agents differ. Furthermore, socio-technical systems evolve, which implies that (some) actors have the ability to learn. This also is an indication that the strength of the relations between variables may vary.

In order to overcome the shortcomings of the traditional methods, Chappin (2011) designed an new experimental method, the *Dynamic Path Approach*. Based on a large data-set (3000 independent runs, 150000 data points), generated from an agent-based model, Chappin was able to estimate the relations of a simple causal model 1) for all time steps together *and* 2) per time step. The model was able to analyse that the relation between two variables changed significantly over time: the predictors were time-dependent.

The Dynamic Path Approach, thus, provides the possibility to examine behavioural changes during a game, something that is not possible with traditional statistical applications. This can be insightful in the actual mechanisms that cause the (system)behaviour. However, this method is still highly experimental and can only be applied to very small, simple systems. Furthermore, the amount of data points needed is huge. These aspects cause the method, on this moment in time, not to be usable yet. However, it is important that research will be done on more advanced data analysis tools, in order to capture the actual dynamics of socio-technical systems.

6.3 Conclusion

Within the context of data collection, there are several aspects that explicitly affect the validity and the feasibility of the proposed data collection tool:

- Not every type of variable can be measured with every collection method.
- Design choices have to be made about the structuredness of data collection.
  - Unstructured methods have
    - open questions/items
    - a high flexibility and nuance
    - low preparation costs
    - high process costs.
  - Structured methods have
    - closed questions/items
    - a low flexibility and nuance
    - high preparation costs
    - low process costs.
- There are multiple data collection methods available. The most common methods, which are likely to be used in games are:
  - Observations. Main characteristics of this method are:
    - The method requires an observer, or instruments that administer the relevant information.
    - The amount of observed variables must be manageable for the observer.
    - The quality of the data depends on the subjective interpretation of the observer.
  - Questionnaires. Main characteristics of this method are:
    - Questionnaires may have an disturbing effect on the game.
    - A balance is required between the size and frequency of the questionnaires and the specificity of the items.
  - Interviews. Main characteristics of this method are:
    - The method requires a trained interviewer.
    - The method is flexible.
    - The method is costly.

Within the context of data analysis, there are several aspects that explicitly affect the validity and the feasibility of the proposed data collection tool:

- Generally, data analysis methods can be structured into qualitative and quantitative methods.
  - Qualitative methods:
    * are necessary to determine the general structure of rules for agents based models.
    * are usually unstructured.
    * are generally time-consuming to process.
  - For qualitative methods applies, that
    * they are necessary to determine the statistical significance effects.
    * the reliability, the power, and the sample size of a test are interrelated
    * the sample size increases, as the number of variables increases.
- Which method can, or should be used is very context-dependent.
- Traditional statistical methods are not suitable to gain specific insight in dynamic behaviour.

Chapter 7

A design framework for the data collection tool

In this thesis we discussed using a game as a data collection tool. We have seen that, in order to do this, three general requirements must be met. Firstly, the game must be able to simulate valid, i.e. sufficiently realistic, behaviour. Secondly, this behaviour must be measured, and finally, the generated data must be analysed. In the previous chapters, we discussed all these categories individually. This chapter elaborates on the interconnectedness between them. All these elements are combined in a general design framework. This can be found in Section 7.1. Section 7.2 elaborates on the operationalization of this framework. Finally, the conclusions of this chapter are presented in Section 7.3.

7.1 Trade-offs between the elements of the data collection tool

The three requirements of a data collection tool are data generation, data collection, and data analysis. In order to meet these goals, design choices have to be made that affect the validity and the costs of the tool. These choices are the result of trade-offs between those aspects, and the availability and restrictions of methods. We have seen, for example, that not every type of behaviour can be validly simulated, and that methods for both data collection and data analysis are limited.

However, the design of the data generation tool (the game), the data collection method(s), and the data analysis method(s) is no isolated, iterative process. The total costs and validity of the tool are not just a summation of the best designs within each category, because design choices within one category may also have implications for the design choices in other categories, and thus on the costs and validity of the data collection tool as a whole. In other words, there are trade-offs and restrictions *between* the design steps with regard to data generation, data collection, and data analysis. Therefore, the designer of the data collection tool must, on beforehand, carefully plan which variables will be analysed, how these will be formalized and operationalized, which methods will be used to collect the data, and which methods will be used to analyse the collected data. Five of these trade-offs are described below.

The number of participants bounds the types of data collection methods Not all data collection methods are equally labour-intensive and costly. Interviews and observational research, for example, do have higher operational costs compared with questionnaires, because more employees are required to conduct the interviews or to observe.

Furthermore, unstructured methods have more operational costs, and are more time intensive compared with structured methods. Because real-time observers do have a limited cognitive capacity to analyse the game, the number of observed variables, and the number of participants, per observer must be limited. These aspects imply that when the total number of games increases, or the total number of players per game, the number of data observers and interviewers increases. In practice, this means that these collection methods are not feasible because of the high costs. Other collection methods, with lower operational costs, e.g. structured questionnaires, can be used to overcome this problem.

The flexibility of possible behaviour interferes with the data collection methods Free-form games are much more flexible compared to rigid-rule games, because players have the ability to invent some of the rules while the game is played. This results in games in which the processes and the outcomes, are much more diverse, and possibly more realistic, because they match the free-form nature of the real world. Players are less bounded by restrictive rules, and have more possibilities to anticipate freely on the events and dynamics of the game (i.e. show 'rich' behaviour). This, however, has the direct consequence that fully structured data collection is not possible, since not all end states can be thought out on beforehand. Free-form games, thus, are harder and more costly to monitor. The more freedom a player has during game-play, the less structured data collection must be. A trade-off, thus, emerges between the flexibility of players' behaviour (and the validity of the tool) on the one hand, and the ease and ability to monitor (and the related costs) on the other hand.

The number of players and the statistical analysis are interconnected As is explained in Section 6.2, every statistical analysis requires a minimum sample size to result in sufficiently reliable analyses, i.e. statistically significant conclusions. Since game-players generate the required data, the sample size is connected to the number of players of the game, as well as the number of plays. Therefore, depending on what is leading, either the minimum number of plays and players depends on the required amount of data, or the statistical analyses are bounded by the number of plays and players.

The structuredness of the data collection and the statistical analysis are interconnected The types of data analysis that can be performed, depend on the characteristics of the data, and thus on the data collection methods that are used. In order to use quantitative methods for data analysis, the data must be expressed in numerical terms. This implies that either structured forms of data analysis must be used, or the data must be coded up to numerical terms.

The size and level of detail of a game are interconnected with data collection and data analysis The more holistic and detailed the reference system is modelled, the more variables there are to influence the simulated behaviour. When one wants to take these variables into account, these should be measured and analysed. This results in more work with regard to data collection. Furthermore, testing statistical models with more predictors, requires more data and thus more players. Another relevant aspect is that more variables may lead to a more complex causal structure. This makes the data harder to analyse by means of traditional statistical methods.

As becomes clear, neither the game, nor the data collection method, nor the data analysis method is per definition leading in the decision which is the most suitable design. The three aspects all are interconnected via several ways. Design choices may have direct or indirect consequences on later design choices, and several trade-offs have to be made, both within *and* between the three categories. All these aspects must be aligned with each other, in order to come to a tenable and useful design for the data collection tool. This interconnectedness is graphically represented in Figure 7.1.

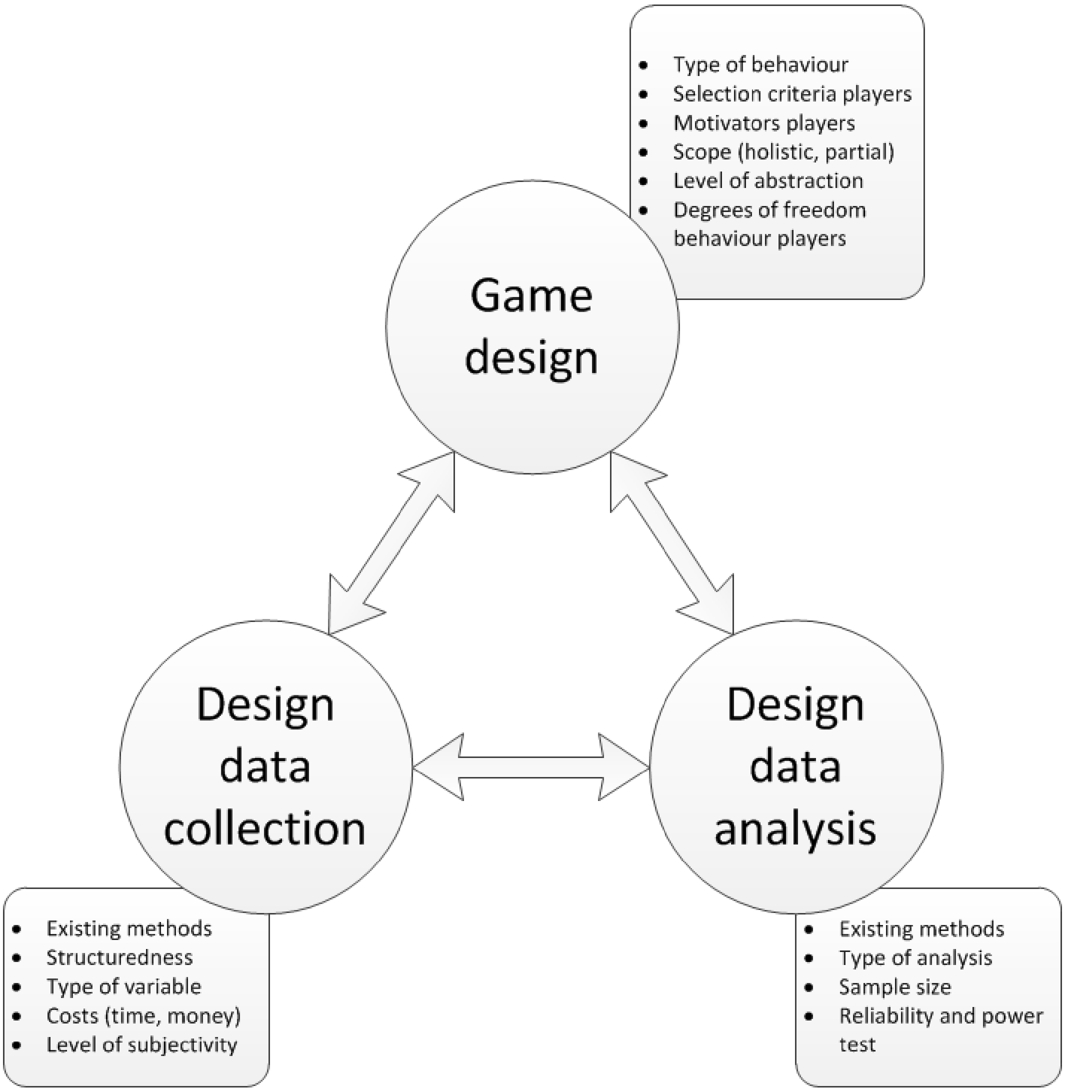

Figure 7.1: A design framework for using gaming as a data collection tool.

This design framework can be used for two reasons. Firstly, it supports the modeller in designing a valid data collection tool, as it presents several relevant design aspects, that influence either the costs, or the validity of the model. During the design process all these aspects need to be points of attention. It is not said that this is an exhaustive list. However, based on this work we can say that at least these aspects, do play an important role. Follow-up research should be done to supplement this list. Secondly, when the framework is operationalized, it can be used to structure the interdependencies during the design of the data collection tool, and provide an overview and justification for the design choices made. In the next section we elaborate on the operationalization of the framework.

7.2 Operationalization design framework

The interconnectedness between the design choices of the game, data collection and data analysis has direct consequences for the design process of the data collection tool as a whole, and the estimation whether the tool is usable and feasible in a specific situation. We recall from Section 4.3 that the use of the tool is driven by one or more specific questions, concerning the design of agents for agents-based models. Ideally, the first step of the design process is the selection of the appropriate statistical methods, in order to fulfil this goal. Subsequently, this design choice would result in specific requirements for the type and amount of data, which would, in turn, results in specific requirements for a game. Within these limitations, a game could be designed, in order to generate the desired behaviour (see Figure 7.2). In this sequence, it would be relatively easy to determine the costs, and thus to gain insight in the feasibility of using the tool.

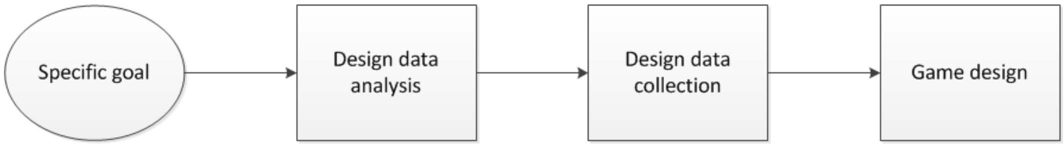

Figure 7.2: The ideal design process of the data collection tool.

However, given the limitations and interconnectedness of the design elements, the design process is a far more complex process (see Figure 7.3). Still, the design process is driven by a specific goal. Because we have seen that not every type of behaviour can be simulated validly by means of a game, the first step is to identify whether the tool is usable. If this is the case, the complex design process of the game starts. During this process a balance should be found between the costs, and the validity of the tool.

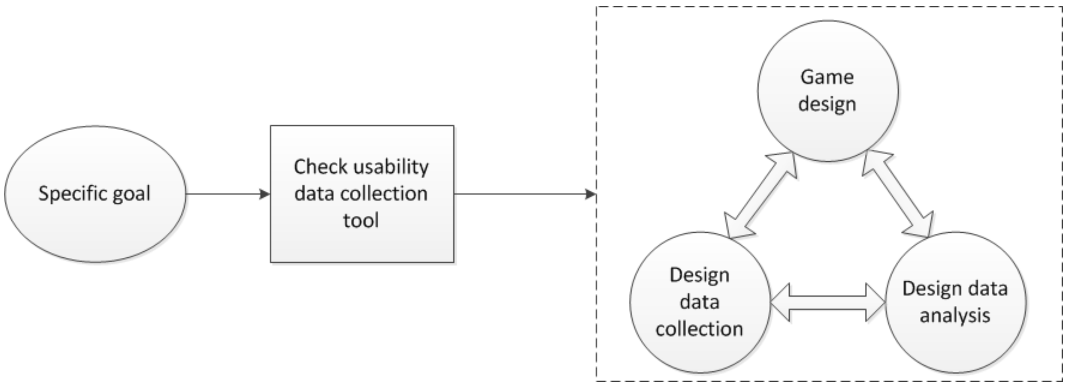

Figure 7.3: The actual design process of the data collection tool.

The ultimate goal to use a game as a data collection tool is to design rules in order to improve an agent-based model. The context of this improvement is relevant for determining the threshold for the (maximum) costs, and the (minimum) validity of the tool (see Section 4.4 and Section 4.5). For example, when the outcomes of the model have large (financial) consequences, or are highly dependent on the specific rules one tries to design, it is likely the data collection tool is allowed to cost more, in comparison to relatively unimportant models. Likewise, the minimum amount of validity (i.e. the realism of the generated behaviour and data), for example, depends on how much information is available via other means. Each design step affects the time that is required to design and operationalize the tool, and the (expected) costs. These can either be design costs, or operational costs, or costs related to data analysis. Furthermore, each design step affects the general validity of the tool, via the psychological realism, the structural validity, and the process validity. As explained in Section 7.1 the design steps are interconnected and influence each other. In case the combination of all design steps is sufficiently valid, and the tool is able to generate, collect, *and* analyse the behaviour of interest, the tool is suitable to use. Whether it is feasible to actually develop this tool, depends on whether the costs of this design do not exceed the threshold. A graphical representation of the operationalization is given in Figure 7.4.

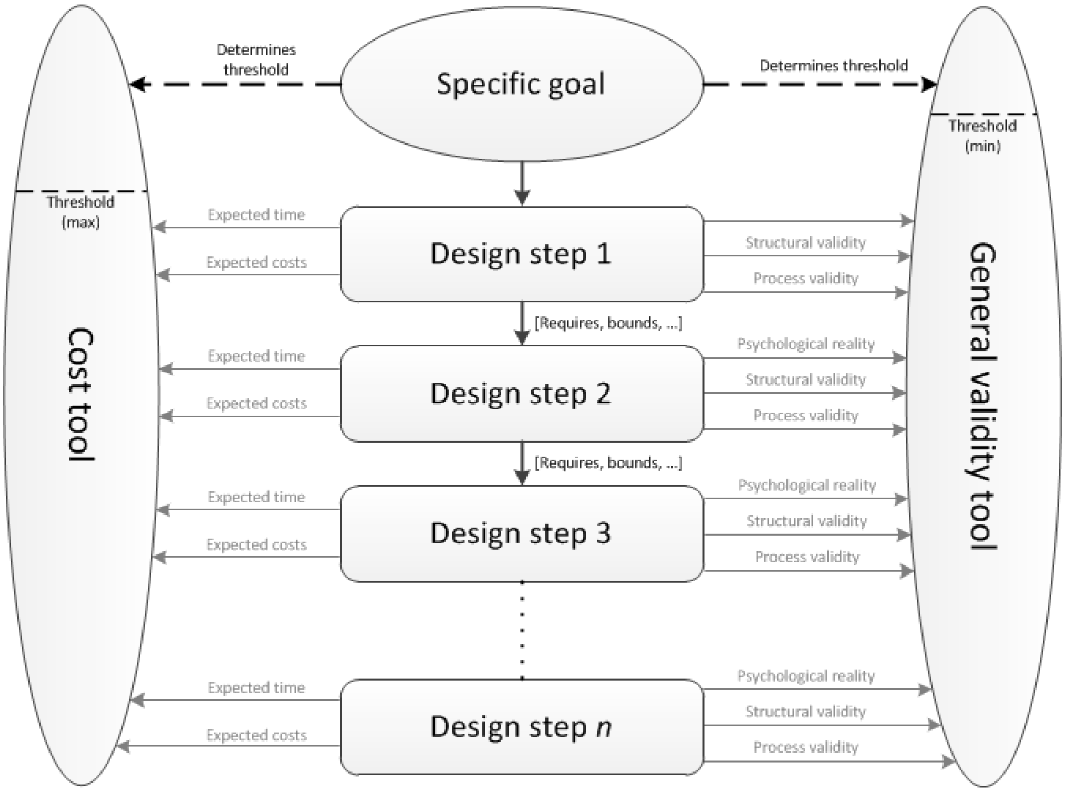

Figure 7.4: A structured operationalization of the design framework of the data collection tool.

Given the large diversity of variables, an infinite number of combinations is possible, which makes a detailed elaboration on the design steps difficult. However, based on the previous chapters, several general remarks can be made concerning the design choices and the feasibility of the data collection tool:

Binding conditions for designing the behaviour The first design choice always relates to the type of behaviour that one intends to simulate. Is it possible to do this? And if so, under which conditions? When the type of behaviour cannot be validly modelled, it is of no use to design the data collection tool. If the behaviour of interest can be modelled by means of a game, but under specific conditions, (as is the case, for example, for habitual behaviour), these always must be met. These binding design choices may have significant consequences for the design as a whole.

Determining the feasibility of the data collection tool As explained earlier in this section, the interconnectedness of the design aspects makes it difficult to make clear estimations about the usefulness and feasibility of the data collection tool. However, several interdependencies are specified in this chapter. This offers the possibility to do 'quick scans' to see whether a data collection tool is suitable to use, given the goals. Several aspects that can be used in these quickscans are discussed below.

Estimating the maximum number of players As is discussed in Section 5.1 there are different types of selection criteria for players of the game. Furthermore, there is a trade-off between the strictness of selection criteria and the number of potential players. In some situations, it may be required to use the most strict selection criterion, namely only playing with actual stakeholders from the reference system. Assuming that every stakeholder plays the game only one single time, the maximum number of players, then, is bounded by the number of stakeholders. By estimating this number, the direct consequences on interconnected design choices can be assessed. In case there is just a small group of stakeholders, for example, the number of quantitative methods for data analysis will be minimal. Comparing those consequences with the intended goals of the analysis provides insight in the usefulness and the feasibility of the data collection tool.

Assessing statistical guidelines In case one is interested in data analysis by means of quantitative methods, he may consult one of the guidelines available, concerning the required sample size and quality of data of statistical analyses (see e.g. Field, 2009). Generally, these guidelines are very clear. When these requirements are taken into account, there can be roughly estimated whether these requirements can be met within a reasonable amount of time and costs.

Limits to the amount of unstructured data collection In Section 6.1 we discussed several data collection methods. One of the most important aspects with regard to the costs (and thus feasibility), is the structuredness of the method. With regard to questionnaires, Cohen et al. (2007) described a simple rule of thumb to guide the decision which type to use: "the larger the size of the sample, the more structured, closed and numerical the questionnaire may have to be, and the smaller the size of the sample, the less structured, more open and word-based the questionnaire may be" (Cohen et al., 2007, p. 320). This rule of thumb can also be applied other data collection methods. This implies that the number of games or players, that can be analysed with unstructured data collection methods, is limited. Furthermore, one must take into account that not every type of variable can be analysed with every data collection method. Thus, in case the goal of the data collection tool cannot be reached with either few players, that are analysed with unstructured collection methods, or with structured collection methods, using the tool to design rules is not feasible.

Feasible data collection methods In line with the previous paragraph, a more general remark can be made about design choices with regard to data collection methods. The fixed costs of structured data collection methods are relatively high compared to the fixed costs of unstructured data collection methods. The reverse is true for the operational costs. Therefore, it is clear that structured methods become financially more attractive, as the number of players increases. More research should be done to the fixed and operational costs of all data collection methods, to get a sense for the switching point.

Collecting data by means of crowdsourcing As we have discussed in Section 3.4.2, games can be used as a form of crowdsourcing in order to collect data. In theory, this can be suitable way to collect large amounts of data. However, it order to make this method successful, several things have to be taken into account. As explained in Section 5.1.2, players must be sufficiently motivated to start, and to keep playing the game. This implies that the platform from which the games are hosted must be sufficiently known, and the game must be fun to play. Furthermore, the game must be easy to understand, and should not take too much time, so that these aspects are no entry barrier for potential players. This implies that the game must not be too detailed.

7.3 Conclusion

- Game design, design data collection, and design data analysis, that altogether form the data collection tool, are interconnected.
- Design choices within one category, may have implications, direct or indirect, on other design choices, both within that design and in the other.
- Neither the game, nor the data collection method, nor the data analysis method is per definition leading in the decision which is the most suitable design.
- Whether the use of a game as data collection tool is feasible and useful depends on the costs of each design step and the (expected) quality of the generated behaviour and data. These aspects depend on the goal and the context of the agent-based model.
- The design process of the data collection tool is very context-specific. However, based on this work, several general remarks can be made:
  - The first design choice always relates to the type of behaviour that one intends to simulate. Some types of behaviour are possible to simulate in a game, others are not. For some types of behaviour there are conditions that must be met, in order to validly simulate the behaviour.
  - Given the high amount of context-dependency, the feasibility of the data collection tool is hard to estimate. However, based on several interdependencies 'quick scans' can be made. These can be based on:
    - an estimation of the maximum number of players. This bounds the number of data and, thus, the statistical methods.
    - an assessment of the statistical guidelines. Statistical tests have clear requirements that should be met.
    - an estimation whether it is possible to fulfil the goal of the tool, either with few players, that are analysed by means of unstructured collection methods, or with structured collection methods.
  - Structured methods become financially more attractive, as the number of players increases.
  - When data is collected by means of crowdsourcing, several aspects are relevant:
    - The game should be fun to play.
    - The game should not be to complicated.
    - The game should not take too long.

Chapter 8

Conclusions and recommendations

This chapter provides the general conclusions and recommendations of this thesis. Section 8.1 answers the main research question, and presents the main findings of this thesis on the basis of the three sub-questions as put in Section 1.4. Section 8.2 critically discusses the results of this work, and provides recommendations for further research on this topic. Finally, Section 8.3 concludes this chapter with a personal reflection on this work by the author.

8.1 Conclusions

In this thesis, we explored a way to aid designers of agent-based models to model agents in such a way that they show more realistic behaviour. We argued that insufficient realistic behaviour from agents may lead to invalid modelling results on both agent-level and system-level. This research aimed to acquire insight in the possibility and feasibility to use gaming as a tool to support the design of agents for agent-based models. The central research question was:

> ***To what extent can gaming contribute to the definition of realistic behavioural rules for agents in an agent-based model, within the context of modelling socio-technical systems?***

Overall, we can conclude that, theoretically, games *can* contribute to the definition of realistic behavioural rules of agents in agent-based models, within the context of socio-technical systems. We have shown this by comparing some of the main problems and challenges of agent-based modelling with potentially helpful characteristics of gaming. A comparison of the design processes of both methods showed, several combinations in which games can support the design of agent-based modelling. In this thesis we elaborated on the application that we believe is the most fruitful in supporting the definition of realistic behavioural rules, namely using games as a data collection tool.

It has appeared that not every type of behaviour can be validly simulated in a game. Furthermore, when a game is used for this application, a number of interconnected design choices and trade-offs emerge, with respect to the costs and benefits of the application. This makes the design of the data collection tool very complex. Whether, and how much the data collection tool can contribute to the definition of realistic behavioural rules, is very context dependent.

In the remainder of this section, the main findings of this thesis are presented on the basis of the three sub-questions.

1. *In what way can gaming contribute to the definition of realistic behavioural rules for agents?*

Based on an extensive literature research, relevant challenges and problems of agent-based modelling, in the context of modelling a socio-technical system, were identified. One of the main challenges includes converting real word phenomena to source code for agent-based models (i.e. the design of rules). Currently, the design of (the behaviour of) social entities in agent-based modelling, is mostly based on interviews and literature studies. These methods entail some problems. When interviews are used, the modeller is dependent on the information the interviewee presents. This information is in many cases, either intentional or unintentional, not (fully) correct. Reasons include that an interviewee may be biased, may be not aware of his own decision making behaviour, or may intentionally provide incorrect information. When rules are based on a literature research, the problem arises that studies within social and behavioural science, because of their analytical nature, mainly describe general behavioural patterns (i.e. context-independent behaviour). However, when designing agent-based models, we are interested in actual behaviour within a certain context. This leaves a gap between the available and desired information. This leads to a formalization problem for modellers.

Several characteristics of gaming provide a theoretical foundation for how this method can be used to support the definition of realistic behavioural rules of agents:

- Because humans, and not agents, make decisions, social complexity and social rationality play a more realistic role in gaming simulations, compared to computer models. This may result in more realistic states and outcomes with regard to the social aspect.
- It is possible to perform experiments in which games function as semi-structured environment. The adjustibility of the game elements allows us to replicate the reference system, in order to deal with the context-specificity of behaviour.
- Gaming simulations provide the possibility to examine actual behaviour.

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 to fill in the gap between an analytic analysis of behaviour and applied model-design, as it functions as a context-specific experiment.

2. *In what way can gaming contribute to the definition of realistic behavioural rules of agents?*

The design frameworks of agent-based modelling and gaming both consist of four similar phases: 1) a problem identification phase, 2) a system analysis phase, 3) a model design phase, and 4) a model development phase. Games can contribute to the definition of realistic behavioural rules of agents via the three latter phases (see Figure 8.1).

- When games are used to support the system analysis phase, they help to identify the internal structure of the system. This includes identifying the main actors and their behaviour, the relationships between those actors, a specification of the actions performed, and a description of the environment in which the actors are performing. A well performed and complete systems analysis forms the basis of realistic rules.

- When games support the model design phase, they can be used to simulate the reference system in order to generate data that are used to formalize and to quantify the relations of the model (i.e. to design rules).
- When games are used to support the model development phase they can function as a way to validate the agent-based model by means of model replication.

In this thesis we chose to elaborate on the option where the game functions as a data collection tool, because we think this is the most fruitful, given the goal to design rules for agents in agent-based models, to make them behave more realistically. The gap between general knowledge about how agents behave and the implementation of precise rules in models is large. In case games can function as a valid data collection tool, rules can be based on this, which is very helpful in overcoming some of the design and formalization problems of agents.

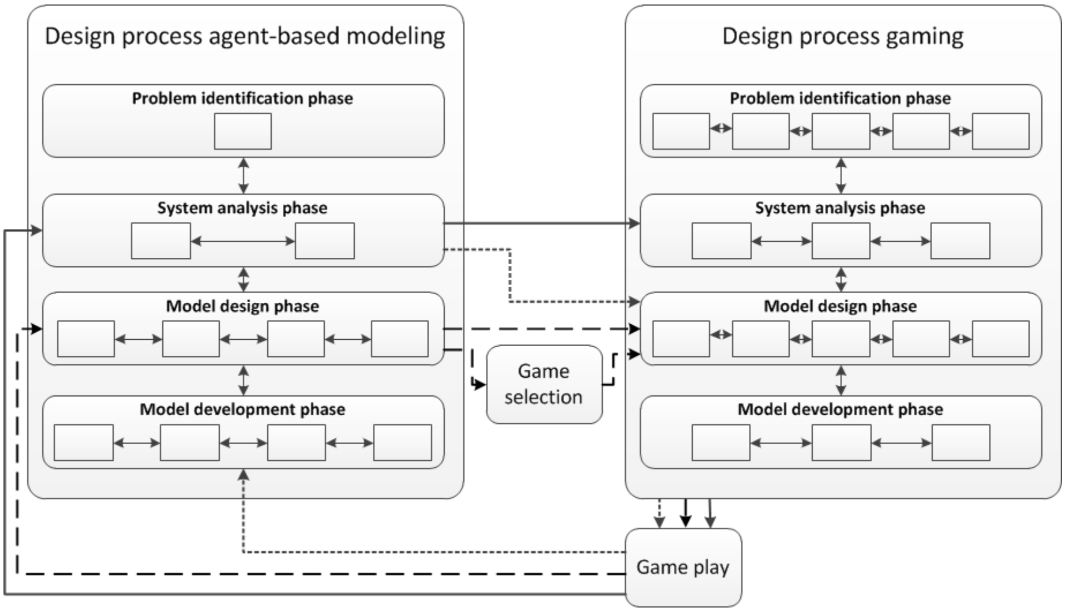

Figure 8.1: A combination of the design processes of agent-based modelling and gaming

3. *What are the most relevant aspects that must be considered when designing a game that can be used as a data collection tool?*

When a game is used as a data collection tool, there are three basic requirements that must be met. One must 1) be able to generate valid data, 2) be able to measure the desired data, and 3) be able to analyse the data. Whether the use of a game as data collection tool is feasible depends on whether these requirements are met, and on the (expected) quality of the generated behaviour and data. Whether the data collection tool is useful, also depends on whether the costs of the tool are in proportion with the quality of the data.

Several aspects of game design, data collection and data analysis affect the validity and costs of the data collection tool. The most important aspects can be found in the design framework, presented in Figure 8.2. Choices within one design (game design, design data collection, or design data analysis), may have implications, direct or indirect, on other design choices, both within that design and in the other two. This makes the design process of the data collection tool very complex. Neither the game, nor the data collection method, nor the data analysis method is per definition leading in the decision which is the most suitable design.

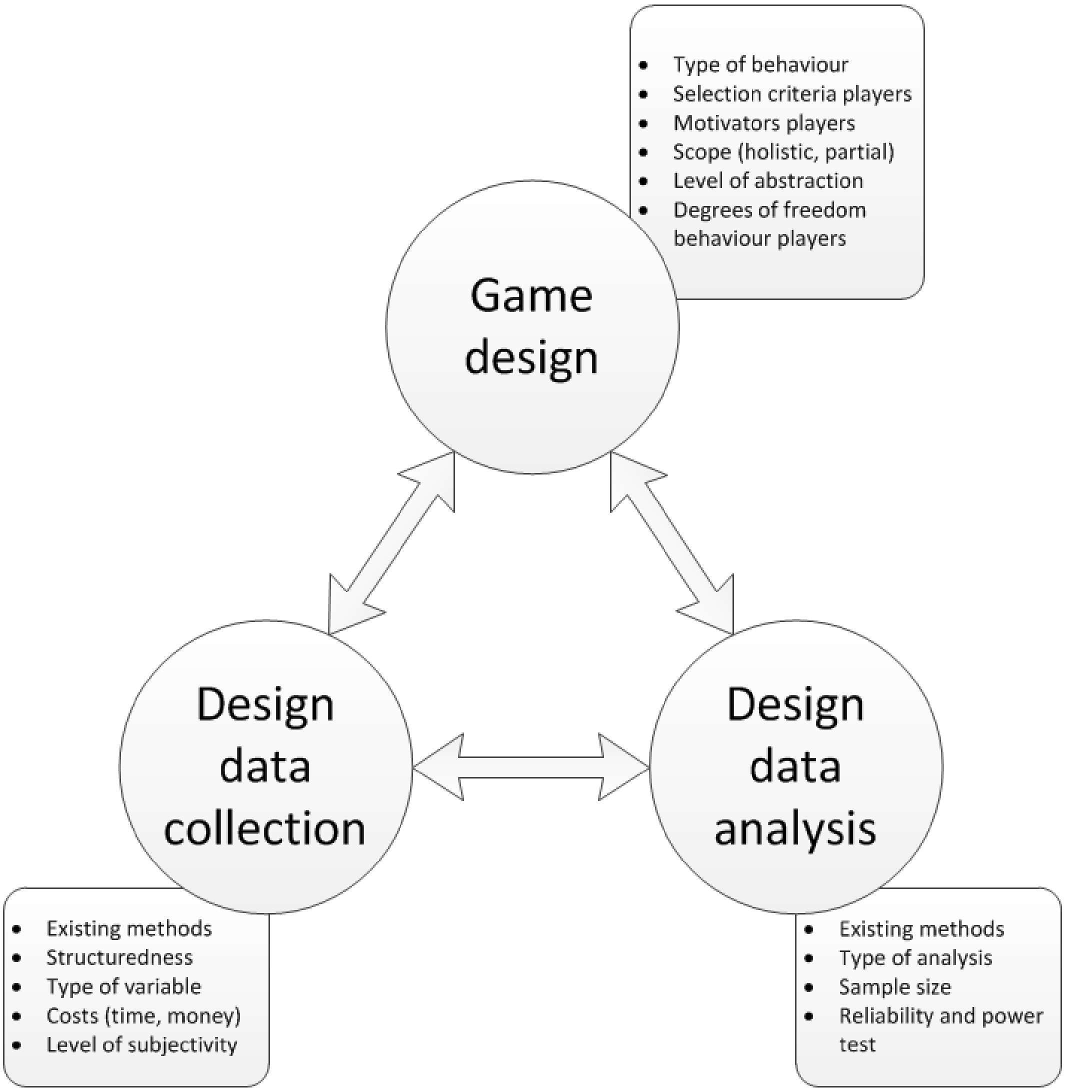

Figure 8.2: A design framework for using gaming as a data collection tool

8.2 Discussion and recommendations for future work

This thesis proposes a new, specific application of games, namely using them as a data collection tool to support rule design of agent-based models. A framework is presented that supports the modeller in designing a valid data collection tool, as it presents several relevant design aspects, that influence either the costs, or the validity of the model. Furthermore, the framework can, in operationalized form, provide a structured overview and justification of the design choices. This work provides a good insight in the potential contribution of gaming to the definition of realistic behavioural rules for agents in an agent-based model. However, some critical remarks must be made on the research done. Also, follow-up research is required to get a more nuanced an complete picture of this research area.

Practical applicability One of the main limitations of this work is that the basis for the argumentation is restricted to literature research, instead of practical experience. This was inevitable, given the lack of a decent theoretical foundation and the novelty of the research topic. However, the most important requirement of a support-tool is its practical feasibility. Because no actual implementation of the proposed data collection tool has been realised so far, the first follow-up research should be the development of a proof of principle for the tool, to show that it can be applied in practice. Also, this research can reveal practical difficulties and give a better indication of its feasibility.

When the applicability of the method has been proven, one or more studies should be done, to see to what extent the tool is applicable. It is reasonable to assume that different characteristics require a (somewhat) different design approach, or that certain combinations are required, or not possible. A wide range of games, 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 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.

Usefulness of the method When a new methodological tool is introduced, in addition to its feasibility, its usefulness is a crucial aspect. The usefulness of a tool must, per definition, be seen in the context of its purpose, which is, in this case, to support the model design of agent-based models. More specifically we aim to use the tool to collect data, in order to design rules for agents that make them behave more realistically. Two important assumptions that (in theory) justify the proposal of this tool are, that 1) the traditional analytical methods to design rules that represent social behaviour, namely literature studies and interviews, are not optimal and 2) currently, (partly because of this) the rules of agents in many models do not lead to sufficiently realistic behaviour. The main assumption about our data collection tool is that it provides improvement.

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. As described in Section 4.4, a new 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.

Individual and institutional behaviour In this thesis, no explicit difference has been made between different types of actors. This is a topic that deserves some extra attention in future research. One of the differences that may be relevant is between individual humans and social institutions, e.g. firms, governments, etcetera. We have implicitly assumed that these types of agents behave more or less the same, at least in their irrationality and diversity in behaviour. This assumption is not unfounded, since, in the end, it will always be individuals that make the decisions. However, it seems reasonable to assume that institutions make more considered decisions, especially when they relate to their core activity. Electricity companies, for example, do not base the price of their product on simple heuristics, but on complex algorithms. These decisions, thus, do not have to be identified and simulated by means of a game, since this can be done with interviews. However, although these types of actors can be assumed to be more rational, it would be naive to consider them as optimal and consistent decision makers. It is hypothesised that decisions by individuals are more influenced by their cognitive inability to make optimal decisions, while institutional actors are more influenced by strategic behaviour and the political arena. Follow-up research is required to provide some insight in this matter.

The playability of the game An issue that is left out of scope within this thesis are 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.

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).

Formalization problems due to ill-defined concepts Another aspect that affects the success of the data collection tool is more fundamental in nature. We have seen that there are several ill-defined concepts within social science. These are concepts for which there is no general agreement about what they exactly are, and what they consist of. This makes them hard to formalize and operationalize for specialists, and even harder for modellers who are not familiar with the corresponding (social) research field. The fact that they are ill-defined, however, does not diminish their importance. Trust, for example, is an ill-defined concept (Van Os, 2011b), but plays a crucial role in many situations, e.g. negotiations, and purchases. Likewise, we have referred several times to 'social laws'. Basically, these can be considered as ill-defined mechanisms within social science.

The data collection tool does not provide a solution for ill-defined concepts and mechanisms. As explained, design choices concerning the formalization of these concepts need to be made before they are implemented in the agent-based model and game, otherwise they cannot be measured. The consequence is that modellers are forced to formalize ill-defined concepts in their own way. These formalizations are, generally, not extensively validated, which raises questions about the validity.

An additional problem that may arise is the need for a large sample size, as the results of the soft nature of social laws. Many aspects may appear to be influential social laws. When these formalizations are tested, the amount of required data significantly increases as the expected number of predictors increases. This very soon leads to the requirement of an infeasible amount of data. This leads, thus, to the pragmatical problem of the requirement of a large sample size.

These problems can be decreased, when a theory is established *and* decently formalized and operationalized. An excellent example is the prospect theory by Tversky and Kahneman (1979). An elaboration of this theory can be found in Appendix D. Based on research to heuristics and biases in human decision making (which identified clear mechanisms, but did not formalize those, conform the 'social laws') Tversky and Kahneman formulated the prospect theory, and later the cumulative prospect theory. This descriptive theory posits

> [...] that individuals evaluate outcomes with respect to deviations from a reference point rather than with respect to net asset levels, that their identification of this reference point is a critical variable, that they give more weight to losses than to comparable gains, and that they are generally risk-averse with respect to gains and risk-acceptant with respect to losses (Levy, 1992, p. 171).

All these features are reflected in a value function that contained a limited number of parameters. It is, by no means, stated that these parameters are easy to measure. However, at least a modeller knows what he has to measure in order to implement a decision mechanism based on the prospect theory. Furthermore, many scientists from various disciplines, have done research on this equation, and were able to improve it, due to the fact that is was formalized.

The presence of such ill-defined concepts and mechanisms causes problems for modelling social entities and behaviour. The quality of simulations of social processes suffers from this problem, because questions can be raised with regard to the validity of the operationalizations. This also affects the usability of the data collection tool. This is an extremely challenging problem to overcome. It requires a large effort, by both social scientists and modellers, given the difficulty of the topic and the large amount of work.

8.3 Personal reflection

This report presented the main result of the master's thesis project I performed, at the final stage of the MSc programme System Engineering, Policy Analysis and Management.

The research process, in combination with my bachelor's thesis psychology took about one year. In this section I will provide my personal reflection on this work, both on my research process, as well as on the outcomes.

Research process This work started with the search for a suitable topic for this thesis. I had no clear picture of what I wanted: "Something with agent-based modelling" (since the experiences with this method during courses and projects earlier that year stimulated me), "but also something new" (since there are so many interesting fields of research to explore), "and I am also studying psychology, and I'd like to combine things". Looking back on my final topic, things worked out very well: a multidisciplinary research, driven by a modelling problem. I learned a lot of new things about the fascinating fields of gaming, and artificial intelligence, and I gained better and deeper understanding of the fields of agent-based modelling and psychology. For a while it seemed I was actually being able to combine my bachelor thesis psychology with this work. Unfortunately, due to scope changes, this fusion became less practical and feasible (although it appeared, scientifically seen, still useful!). Oh well.. At least I tried!

On the whole I am very satisfied with the research process. I enjoyed the freedom my supervisors gave me. This resulted in relatively few (planned) meetings, but I regularly contacted my supervisors, and other researchers at the faculty, with brief or less brief questions. Since I was very happy to have a desk at the section of Energy and Industry, this was fairly easy to do. In situations I really struggled with topics, e.g. the determination of my scope, I contacted my supervisors in time. Overall, I can say that I have never felt totally lost during this project.

The project took more time than initially planned. Firstly, this was due to a (too) ambitious planning in which I underestimated the time I would spend to my bachelor thesis psychology. This related to the work itself, but also to a period of rest I needed after this was finished. Furthermore, due to my perfectionistic nature, it is hard for me, from time to time, to let go, or to make hard decisions and design choices. During this project, I have tried to reduce the negative effects of this characteristic (and I did!), and this learning process takes time, literally. Finally, perfectionism also has its positive side: it drives me to deliver high quality work. Stimulated by the feedback of my supervisors, I decided to spend some extra time on this thesis, in order to improve its content. Overall, I would rather have finished this thesis earlier, but I do not regret the decisions to take some extra time off and 'to go the extra mile'.

Research outcomes When I started this thesis, I envisioned a completely different type of research outcomes. However, in general, I am satisfied with the results. Given the methodological nature of the research problem, and the novelty of (and thus lack of literature on) the topic determining the scope was a challenging process. I have tried to approach the research problem via several different angles, in search of sufficient foundation to start designing. The end-result was far more abstract than initially foreseen. However, in my opinion this was the only right place to start, to make sure that my analysis would be sufficiently tenable (from the perspective of agent-based modelling, gaming and psychology). I believe the outcomes of this thesis can be a useful basis for further research on this topic. Whether the gaming can actually be added to the 'toolbox' of a designer of an agent-based model, depends highly on this future work. Given the nature of design challenges of a data collection tool, it can by no means be considered as the optimal solution to modelling realistic behaviour. However, my estimation is that the tool can be very useful in some situations. However, more strictly delineated research has to be done in order to demonstrate this.

Another implicit, but possibly more important research outcome, is the insight that there is a fundamental formalization problem with regard to psychological theories. Within the field of psychology there is a large amount of excellent research on human behaviour. However, most of this work is not formalized, which makes it hard to implement in models. Therefore, it is understandable that this is not widely done. However, this does not mean that this not *should* be done. Especially, when one is modelling *socio*-technical systems, and one, thus, explicitly acknowledges the importance of taking the social part of a system into account, models should also be based on social sciences. I am not advocating that modellers should formalize all psychological research. What I do advocate is, that modellers have a responsibility in this process, namely acknowledging the importance of a solid social foundation of models, and by asking (or perhaps even demanding) better formalization of existing research within social sciences. In my view, currently, this is not the case, as too often implausible assumptions, such as a fully rational decision maker, are taken for granted, and are too little criticized. Of course, modellers can overcome this problem by explicitly naming the limitations of their model. However, formalization problem stays.

Research implications Using games as a data collection tool, may be a useful tool for the support of more realistic behaviour in agents. As stated in the introduction, this research should be seen as the first of many, on this topic, in order to fully and successfully develop the method. In this thesis, various follow-up research has been proposed that can be performed in order to get more insight in the usefulness and the feasibility of the method. However, as mentioned earlier, using a data collection tool does not reduce the fundamental formalization problem.

This problem can only be solved with the commitment of a large amount of researchers. As may be clear, this problem transcends the field of agent-based modelling, since it can affect all research methods in which social entities are modelled. Given the specificity of the disciplines, resulting in a different view on the matter, the importance of multidisciplinary research is stressed. Developments with e.g. the prospect theory, show that significant progress can be made in this matter. Note that research on this topic is not just of scientific (methodological) value, but also has large social consequences. Many models, on which policy interventions are based, for example, maintain unrealistic assumptions concerning social behaviour.

Researchers at the faculty of Technology, Policy and Management of Delft University of Technology are engaged in analysing socio-technical systems from multiple perspectives, and acknowledge the importance of the 'soft', social side of these systems. Furthermore, they are experienced in various modelling methods. Therefore, in my view, this faculty is particularly suitable to play an important role in the transition to more formalized psychological and sociological knowledge. A close cooperation with other, more analytically focused faculties of behavioural sciences, has the potential to lead to a highly relevant and very successful research programme.

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Appendix A

Synchronizing the design processes of agent-based modelling and gaming

This appendix elaborates on the design processes of agent-based modelling (Section A.1) and gaming (Section A.2). In Section A.3, we conclude that the design processes are comparable to a large extent and identify four similar phases.

A.1 Design process agent-based modelling

Nikolic and Ghorbani (2011) present a methodological framework for the design process of agent-based modelling, within the context of modelling (large-scale) socio-technical systems. This framework is graphically represented in Figure A.1. It consists of five iterative steps, some of which include several sub-steps. In order to reduce confusion between steps and sub-steps, we will, in the remainder of this appendix, talk of five different *phases* all consisting of several *steps*. All five phases will be briefly discussed below. For more detailed information, we refer to the corresponding article of Nikolic and Ghorbani (2011), or to Nikolic et al. (forthcoming).

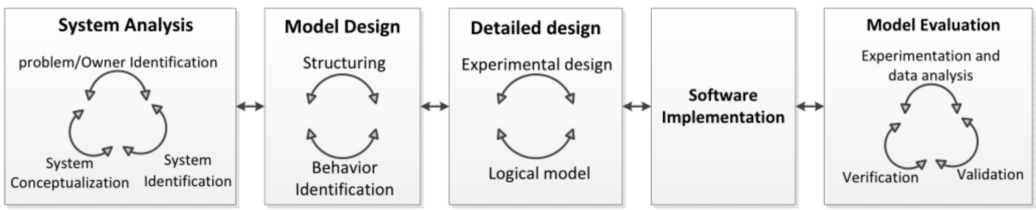

Figure A.1: A design framework for agent-based modelling (Nikolic & Ghorbani, 2011)

System analysis phase The system analysis phase is about understanding the reference system that is simulated by means of an agent-based model. The first step is to identify the problem and the problem owner, in order to determine the scope and the goal(s) of the model. Furthermore, the composition of the system is identified and de boundaries are set. "The goal of this step is to identify the internal structure of the system under analysis in such a manner that complex analysis of the system becomes possible" (Nikolic & Ghorbani, 2011, p. 45). This includes identifying the main actors and their behaviour, the relationships between those actors, a specification of the actions performed, and a description of the environment in which the actors are performing. When the system components are identified, they need to be decomposed into a manageable and understandable structure.

Model design phase The main goal of the model design phase is to translate the concepts of the system analysis phase, into a more explicit form. (i.e. more in terms of a formal software model). The focus of this phase is, like the system identification step, to get a clear picture of what will be modelled. This includes, among others, the classification of (types of) agents and adding hierarchy to the agent and interaction components. Furthermore, this step includes determining on which components will be focussed and which components will be part of the environment of the model. Another step during this phase is the behaviour identification of the artificial entities and the environment. This step is about how model components behave during a simulation.

Detailed design phase In the detailed design phase, the details required to program an actual model are specified. This phase consists of two steps: the logical model formalization and the experimental design. The goal of the logical model formalization is to "make sure that the identified concepts can be understood by a computer, while retaining their originally intended meaning" (Nikolic & Ghorbani, 2011, p. 47). Eventually, every concept identified in the previous phases must be formalized by means of basic elements, that are supported by the used computer language. The goal of the experimental design is to answer the question what it is, we want to measure. Based on this question, hypotheses can be formed and experiments can be designed *how* this can be measured. Common experimental options include runs of time, scenario design and parameter sweeps.

Software implementation phase Based on the three previous phases, the source code needs to be implemented. Nikolic and Ghorbani (2011) lay emphasis on the iterative nature of the design process, which may cause concepts and the design to change due to issues that emerge in this phase.

Model evaluation phase During the model evaluation phase, the model is evaluated in several ways. In practice, these steps are not executed as one phase, but the model is evaluated continuously during the modelling process. An important step of this phase is the verification of the model. Verification is about the question whether the conceptual model is correctly translated into source code. Four main parts to verifying agent-based models can be identified: recording and tracking agent behaviour, single-agent testing, interaction testing, limited to minimal model, and multi-agent testing (Nikolic et al., forthcoming). Another important step of this phase the validation of the model. The validation of a model concerns whether it is an accurate representation of the real-world system, given the intended purposes (Sargent, 1998). Commonly used methods for the validation of agent-based models include historic replay, face validation through expert consultation, literature validation and model replication (Nikolic et al., forthcoming). The final step of the model evaluation phase is experimentation and data analysis. During this step the experiments that are required to give answer to the research questions are performed. Given the exploratory nature of ABMs, usually a large number of simulations has to be performed.

A.2 Design process gaming

Duke and Geurts (2004) present a methodological framework for the design process of (policy) games, within the context of tools that support strategic management. This framework is graphically represented in Figure A.2. It consists of five phases, each including several steps. "In the abstract, the game design process is viewed as sequential [. . .] In practice, the designer may attempt a somewhat more simultaneous solution" (Duke & Geurts, 2004, p. 278). All five phases will be briefly discussed below. For more detailed information, we refer to the corresponding book of Duke and Geurts (2004), or to interpretations of their work (e.g. Peters & Van De Westelaken, 2011).

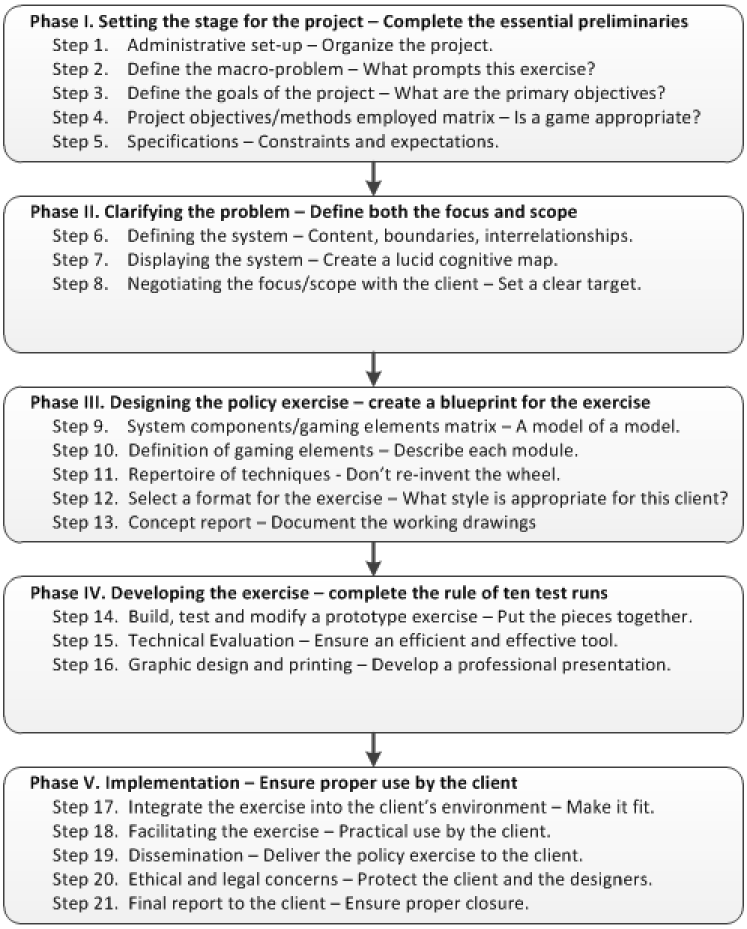

Figure A.2: A design framework for gaming (Duke & Geurts, 2004)

Phase I. Setting the stage for the project In the first phase of the design process of a game, the essential preliminaries need to be completed. The goal of this phase is to clarify the problem, the decision whether a game is a suitable tool or not within this context, the intended purpose of a game (including the constraints), and the expected end-result by the client. Furthermore, in this phase some pragmatical specifications are discussed with the client, e.g. the timeline of the project, the budget, and other resources.

Phase II. Clarifying the problem In the second phase, the problem context is examined. The main goal of this phase is to complete a cognitive map of the reference system. This includes defining and understanding the elements, boundaries and relations of the system. During this phase, one aims to make the description of the reference as complete as possible, such that informed design choices can be made during the design phase of the game. When this step has been fulfilled, the next objective is to develop a graphic representation of this system, and discuss it with the client and relevant stakeholders.

Phase III. Designing of the policy exercise The third phase of the design process consists of the translation of the previous phase into a blueprint for a game. Like every model, a game is a abstract representation of reality. Therefore, an important step during this phase is to reduce this the number of system elements and their complex interrelations to a manageable and playable number. For the validity of the game it is crucial that it contains the key characteristics of the reference system. Therefore, while making this selection, the context of the goal of the game has to be kept in mind closely. Another step within this phase is the format choice of the system elements, and the game as a whole. Answers to questions as "What is possible?" (fundamentally, and given the resources) and "What is appropriate?" (given the wishes of the client) guide these decisions. When these steps have been fulfilled, they are all combined into one consistent whole. This blueprint of the game, then, is discussed with the client and modified in case this is needed.

Phase IV. Developing the exercise In this phase, the game concept of the previous phase is further developed into an actual game. All game elements must be fashioned appropriately into a prototype. This prototype needs to be sufficiently tested and modified. A rule-of-thumb is the *rule-of-ten* that argues that a series of ten increasingly more precise rehearsals should be undertaken, before the game is presented to the client (Duke & Geurts, 2004).

Phase V. Implementation The goal of the implementation phase is to ensure a proper use of it by the client. When the game reaches its final shape, it is calibrated to the specific wishes and goals of the client. Furthermore, the game needs to be transferred to the client. Mostly, this implies that a training is required, for those who will supervise the game as game leader or facilitator (Peters & Van De Westelaken, 2011). Also, a number of concerns should be addressed, including the ethical and legal issues.

A.3 Synchronizing design processes

Despite some minor differences in focus and scope, the design processes for agent-based modelling and gaming are comparable to a large extent. In this section we synchronize both frameworks with each other, so that they are comparable more easily. Thereby we use the first four steps the design framework for gaming as starting point.

Problem identification phase Both methods are used as tools to examine, or to overcome a certain problem. The design of the methods are driven by this goal, and bounded by the resources of the client (or 'problem owner'). Therefore, this should be always the first step of the design process. Both frameworks acknowledge the importance of this step. However, Duke and Geurts (2004) describe this first phase in more detail (namely in 5 steps). However, these steps are not unique, and are implicitly assumed as part of the problem/owner identification step, of the framework for agent-based modelling. Furthermore, Nikolic and Ghorbani (2011) consider the problem identification as part of the system analysis.

To emphasize the importance of this preparatory phase, we decide to follow the structure of Duke and Geurts (2004). The main goal of this phase is to identify the problem and the perspective from which it is experienced. This answer to these questions form the basis for the rest of the design process. For this reason it is named the *problem identification phase*.

System analysis phase The next steps in both frameworks are aimed to create a clear picture of the context in which the problem occurs. In other words: what does the system of interest look like? Both frameworks describe steps that are aimed to identify the relevant actors, relations, boundaries, etcetera. Therefore, there is not much synchronization needed, as the steps already correspond. We use the terminology of the agent-based modelling framework to describe this phase: the *system analysis phase*. This phase includes the system conceptualization and system identification from the agent-based modelling framework, and step 6-8 from the gaming framework.

Model design phase The next steps in both design frameworks focus on the actual design of the agent-based model and the game. As a result, the steps described, are directed towards the specific needs for either a game, or an agent-based model. However, the main principle of these steps is for both methods the same. The main goal of these steps is to 'translate' the relevant real-world aspects, as identified in the system analysis phase, into a model. The question that drives these steps is: how do we represent this system in a model? Therefore, we label this phase the *model design phase*. For the gaming framework, this just means another name for the third phase. For the agent-based modelling framework, this is a merger of both the model design phase and the detailed design phase.

Model development phase The next steps in both frameworks concern the development of the blueprint of the model, designed in the previous phase, into the model itself. Both frameworks have slightly different focus on this process, but the main principles, again, are the same. Nikolic and Ghorbani (2011) consider the software implementation as a separate phase. Furthermore, they specify three different steps as part of the model evaluation. Duke and Geurts (2004) are more brief on this topic and describe the building, testing, and evaluation of the tool as two steps (step 14 and 15). However, this does not imply that these actions are less important. In our opinion the agent-based modelling framework is more precise on this topic. Nonetheless, both frameworks are similar, and can be synchronized easily. Given the iterative character of the building and the evaluation of the model, we consider all steps from the blueprint to the satisfactory completion of the model to be part of the *model development phase*. This, thus, includes building and testing the model. The main question during this phase is, whether the model is build sufficiently well, given its purpose(s).

Model implementation phase The design framework of agent-based modelling ends after the successful development of the model. The framework of gaming consists of an additional phase that describes the steps, related to the implementation of the game, e.g. the transfer to the client. Obviously, these steps are implicitly assumed by Nikolic and Ghorbani (2011) as well, since there is no use for the model without the implementation. In this comparison we only assess the actual design of the model, and, therefore, consider the implementation out of scope.

A graphical representation of all design steps of agent-based modelling and gaming, in the new, synchronized structure can be found in Figure A.3 and Figure A.4, respectively.

The numbers in the latter figure, refer to the design steps of Duke and Geurts (2004) (see Figure A.2).

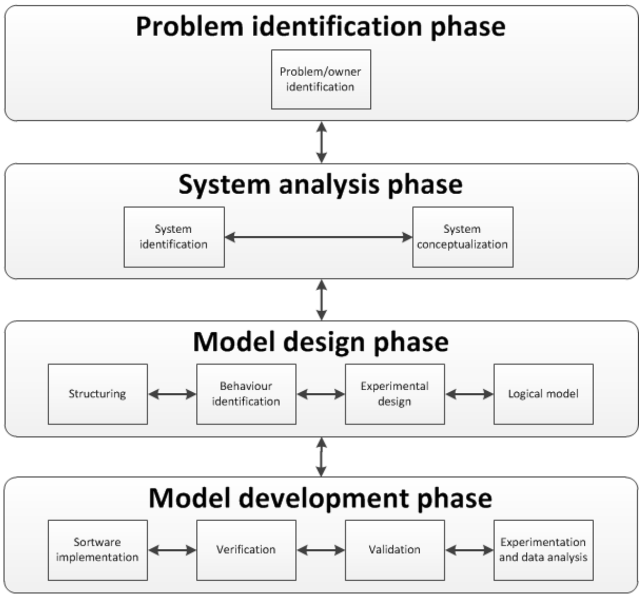

Figure A.3: Synchronized framework agent-based models

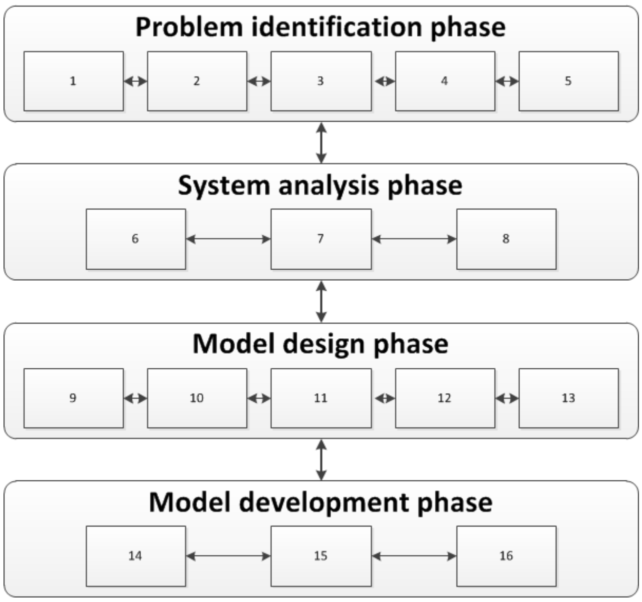

Figure A.4: Synchronized framework games

Appendix B

Clarifying the terminology surrounding gaming

This appendix is an extension of the Section 3.1. Here will be shown how we have come to the working definitions of games and serious games that are used in this thesis. In order gain a good understanding of these concepts, we will start with a brief elaboration of a strongly related concept: play.

B.1 The concept of play

Playing with toys; playing a game; playing guitar; playing the fool; playing around. These are just a few of many examples of how the word 'play' is used in everyday life. Although the word play is often referred to as non-serious concept, this is not always the case. In his influential book *Homo ludens* - Man, the player - Johan Huizinga (1938) elaborates on the importance of play to human development and culture. Despite its importance, it is hard to get a full understanding of the concept of play, due to its broad meaning. However, psychologist J. Barnard Gilmore (1971) notes that "certainly everyone knows what play is not even if everyone can't agree on just what play is" (p. 311).

Many definitions of play have been formulated, e.g. Salen and Zimmerman (2004). For this thesis it is not necessary to compare all of those, and their differences. It is more interesting to see how play relates to the concept of games. Salen and Zimmerman (2004, p. 72) show that games can be subset of play, as well as that play can be an element of games:

> **Games are a subset of play**: Games constitute a formalized part of everything we might consider to be play. Playing catch or playing doctor are play activities that fall outside our definition of games (a contest of powers with a quantifiable outcome, etc.). However, although not all play fits the category of games, those things we define as games fit within a larger category of play activities.
>
> **Play is an element of games**: In addition to rules and culture, play is an essential component of games, a facet of the larger phenomenon of games, and a primary schema for understanding them.

In order to come to a suitable definition of games, we focus on the first relationship. Although we have not yet elaborated on a definition of games (this will be done in the next section), one can understand intuitively that some forms of play can be labelled as games, while others cannot. Activities within this last category are referred to as 'ludic activities', and include, for example, kittens chasing a piece of string and children throwing a ball towards each other. Furthermore, ludic activities in turn are a subset of 'being playful'. This not only refers to playful activities, but includes a certain state of mind, e.g. making jokes or dress in a funny way to make a statement (Salen & Zimmerman, 2004). This last distinction in subcategories is out of the scope of this thesis and we will focus on the question when ludic activities can be considered as game play. This will be discussed in the next subsection.

B.2 The concept of games

The difference between play and game is a subtle one. In some languages, among which, German, French and Dutch, the words for both concepts are identical. This has led to some confusion in defining both concepts. Many attempts have been made to define a game, but none remained uncriticized (Salen & Zimmerman, 2004; Schell, 2008). In introducing and elaborating on family resemblance, Ludwig Wittgenstein (1953, p. 33) even shows that there are fundamental difficulties in defining a game. He argues that games have many common features, but that there is nothing common to all games.

> What still counts as a game and what no longer does? Can you give the boundary? No. You can *draw* one; for none has so far been drawn. (But that never troubled you before when you used the word "game".)

Salen and Zimmerman (2004) structurally compared all elements of eight definitions of games, and found that no single element appeared in all of the definitions. There appeared only a majority agreement for the notion that games have rules and goals. Based on the analysed definitions, Salen and Zimmerman (2004) formulated an own definition of games:

> A game is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome (p. 80).

This definition does not offer a perfect demarcation criterion to make a distinction between games and play (the authors do not pretend it does). However, it covers the most important elements derived from literature, and can function as a suitable working definition for this thesis. Below, there will be elaborated on each individual element from the definition (partly adapted from Salen & Zimmerman, 2004, p. 80).

- **System:** Considering games as systems, aligns well with the systems perspective taken in this thesis
- **Players:** A game is something that one or more participants actively play. To reach the goal of this thesis (extract behaviour from human game players), only games that contain at least one human participant are included[1]
- **Artificial:** "Games maintain a boundary from so-called "real life" in both time and space. Although games obviously occur within the real world, artificiality is one of their defining features."

[1] An interesting, almost philosophical question that is avoided in this way, is whether a 'game' of chess between two computers can be still considered as a game or not

- **Conflict:** "All games embody a contest of powers. The contest can take many forms, from cooperation to competition, from solo conflict with a game system to multiplayer social conflict. Conflict is central to games."
- **Rules:** "We concur with the authors that rules are a crucial part of games. Rules provide the structure out of which play emerges, by delimiting what the player can and cannot do."
- **Quantifiable outcome:** "Games have a quantifiable goal or outcome. At the conclusion of a game, a player has either won or lost or received some kind of numerical score. A quantifiable outcome is what usually distinguishes a game from less formal play activities."

B.3 The concept of serious games

The next step is to define the concept of serious games. Again, literature does not provide us with a generally accepted definition (Susi et al., 2007; Ulicsak & Wright, 2010). One of reasons for this is the variety in definitions of games, as is explained above. However, the nature of these differences between the definitions exceeds this topic.

In 1968, Clark Abt introduced the concept of serious games. His definition of such games was that they:

> have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement. This does not mean that serious games are not, or should not be, entertaining (Abt, 1970, p. 9).

As we have seen in Section 3.2, (serious) games can have many different types of thought-out purposes. The most common purpose is to teach players one or more skills. These include cognitive skills, perceptual skills, motor skills, and social skills (Harteveld, 2011). However, this is not the only type of purpose a game can have. Another example (and the purpose of thesis) is data collection. Therefore, the definition of Abt is considered too narrow.

After its introduction the oxymoron serious games did not really take hold (Mayer, 2009). In 2002 the the concept was reintroduced by the Serious Game Initiative[2], after the computer (game) industry had made significant developments.

> The Serious Games Initiative is focused on uses for games in exploring management and leadership challenges facing the public sector. Part of its overall charter is to help forge productive links between the electronic game industry and projects involving the use of games in education, training, health, and public policy.

Notice that this description explicitly mentions *electronic* game industry, implying that serious games must be computer games. This is another element that returns in many definitions (e.g. Sorensen & Meyer, 2007; Zyda, 2005). However, this element is considered too narrow. There is no reason to exclude non-digital games, since these can have serious purposes as well, e.g. *Hexagon* (Duke, 1975). Furthermore, digital games do no necessarily have an added value over non-digital games. Trade-offs between both types of game have to be made. For example, with digital games very realistic

[2]http://www.seriousgames.org

environments can be created, but this coincides with higher development costs. A far more simple environment (e.g. a card game) may be sufficient and reduce development costs significantly.

Michael and Chen (2006) have formulated a broader definition of serious games, that leaves room for serveral serious purposes and does not exclude non-digital games:

> [serious games are] games that do not have entertainment, enjoyment, or fun as their primary purpose (Michael & Chen, 2006, p. 21).

This definition clearly states that a serious game requires a certain (serious) purpose, other then entertainment. The authors do remark that this does not necessarily mean that serious games are not entertaining, enjoyable, or fun, just that there is some other primary purpose. However, the definition does not specify from who's perspective the purpose of the game is seen: the perspective of the game player or the perspective of the game designer. For example, the primary purpose for players of the ESP game (Von Ahn & Dabbish, 2004) is to play an enjoyable game. It is one of many online games that can be played to entertain yourself. However, the purpose of the designer of the ESP game is to label all images on the Web, in order to improve search engines such as Google. Thus, the purpose of the designer can be considered as serious. The question then is whether this game is a serious game or not according to the definition of Michael and Chen. The fact that this ambiguity is possible makes clear that this definitions needs to be further specified. Susi et al. (2007) provide such a definition:

> [serious games are] games that engage the user, and contribute to the achievement of a defined purpose other than pure entertainment (whether or not the user is consciously aware of it). A game's purpose may be formulated by the user her/himself or by the game's designer, which means that also a commercial off-the-shelf (COTS) game, used for non-entertainment purposes, may be considered a serious game (Susi et al., 2007, p. 5).

This definition solves the ambiguity explained above. Furthermore, this definition includes the possibility to modify existing commercial off-the-shelf games, into serious games when either the designer or the player has formulated a serious purpose.

For this thesis it is only relevant whether the designer has formulated a serious purpose, since the game will be used as a tool to improve agent-based models. This goal requires a structured approach and cannot be reached when only the player has formulated a serious purpose. Therefore this will be removed from the definition. Furthermore, the element of engaged users is considered to be too subjective. Susi et al. (2007) note: "In our view, games should be engaging and motivating, which is advantageous for, e.g., the development of a variety of skills and abilities". This is certainly true, but leads to an arbitrary decision whether game players are engaged sufficiently, and thus whether a game can be considered as a serious game or not. Also, this may lead to the undesirable situation that a game on one moment is a serious game, and on the other moment is not because the players are not motivated enough.

Altogether, these remarks lead to the following definition of serious games that is used in this thesis:

> Serious games are games that contribute to the achievement of a defined purpose, formulated by the game's designer, other than pure entertainment (whether or not the user is consciously aware of it).

Appendix C

Replication of system behaviour

This appendix contains an extension of the the introductory paragraphs of Section 5.3.1 and Section 5.3.2. It provides additional background information on habitual behaviour (Section C.1) and normative behaviour (Section C.2).

C.1 Habitual behaviour

In literature many models can be found which aim to explain and predict the initiation of human behaviour. The most influential and well known theory of how attitudes predict deliberative behaviour is the *theory of planned behaviour* (Ajzen, 1991), which is an extension of earlier work by Fishbein and Ajzen (1975). According to this theory, behaviour is predicted by the attitude toward the behaviour, the subjective norms and the perceived behavioural control. These predictors affect behaviour directly, and also indirectly trough the mediating role of intentions. This theory emphasizes the deliberative character of decisions.

However, decision making is not always a conscious and reasoned process. The majority of people's actions are based on routines and habits, which enables us to perform tasks without attention. Performing certain tasks subconsciously is necessary to save enough cognitive capacity for decisions that do require our full attention. Many research in different fields, has been done to the concept of habitual behaviour. Therefore, it is hard to give a unambiguous definition of a habit. The essence of most definitions is that habits are stable patterns of behaviour resulting from biological and social processes (Aarts, 2009). In this Section we elaborate on habitual decision making behaviour, and explain the implications on validity of a game as data extraction tool when modelling this type of behaviour.

Acquiring habits In general, two different levels can be identified on which habits are acquired: stimulus-response learning and goal-directed learning. Stimulus-response (S-R) learning finds its roots in the behaviouristic school. The most important proposition of this school is that there are no mediating, internal constructs and processes (e.g. perceptual interpretation and categorization, judgement and evaluation, memory, motivation and goal pursuit) needed to explain human behaviour. Any type of learning can be traced back to associations between stimuli and responses. The most important form of learning is operant conditioning, in which a certain response, in reaction to a stimulus, is more likely to occur when it is positively reinforced (e.g. by a reward). A punishment, instead of a positive reinforcer, may cause behaviour to occur less frequently (Skinner, 1938; Watson, 1914). When the time between the stimulus and the reinforced response is limited, and it is clear that the reinforcer follows on the response (it is not 'disturbed' by other stimuli) the two get mentally coupled. On a certain moment, reinforcers are no longer needed to provoke the response to a stimulus; the response has become a habit. S-R learning may be a useful theory to describe the acquisition of simple habits. However, the S-R theory failed to explain complex human behaviour and was soon dominated by cognitive science, that explicitly included internal constructs and processes (Bargh & Ferguson, 2000).

Another way to look at habits is as a form of goal-directed automatic behaviour (Aarts & Dijksterhuis, 2000; Aarts, 2009). This approach does more justice to the fact that complex behaviour can be habitual as well, and that specific habitual behaviour can be flexible, depending on the circumstances. The main assumption of this approach is that actions are directed by underlying higher goals (Powers, 1973). The decision between multiple options to reach a certain goal, starts with a reasoned selection of the alternatives. After repeatedly and consistently choosing the same alternative, both the sequence of behaviour *and* the choice itself will become automated (Aarts & Dijksterhuis, 2000). Thus, patterns of behaviour need to be 'activated' by actually performing the behaviour. Once this is the case, it will be, at least to some extent, automated behaviour.

The behaviour we are interested is, generally, of a lower level of detail than S-R learning is able to explain. Furthermore, the assumption that complex behaviour can be habitual as well, is more in our line of thought. Therefore, we consider, within this thesis, habits as a form of goal-directed automatic behaviour.

C.2 Normative behaviour

Another relevant aspect that possibly influences behaviour are social norms. These can be defined as "the social or explicit rules a group has for the acceptable behaviors, values, and beliefs of its members" (Aronson et al., 2005, p. 250). Research has indicated that witnessing the actions of others can have a powerful effect on (decision making) behaviour (Cialdini et al., 1990; Cialdini & Goldstein, 2004). Also, written information can cause people to behave according to the communicated norm (Parks et al., 2001). The effect of norms on behaviour can occur subconsciously and may be underestimated by the individual (Nolan et al., 2008).

Norms are rather stable, but do change as result of for example. technological developments, interchanging cultures or specific incidents (e.g. terrorist attacks). Furthermore, norms may differ significantly between different social groups, such as cultures, religions, and political convictions. Because of these characteristics it is very hard to make generalizations about norms. However, it is clear that the extent to which norms do influence actual behaviour depends strongly on the 'salience', i.e. the extent to which the norm is visible and noticeable relative to the environment (Cialdini et al., 1990).

In literature, a distinction is made between injunctive norms and descriptive norms (Cialdini et al., 1990). Injunctive norms are shared opinions about desirable and undesirable behaviour. Conformation to these type of norms can occur both consciously and subconsciously. Descriptive norms are norms based on the perception of the behaviour of others in specific situations or based on indirect information about that type of behaviour. Conformation typically occurs via an subconscious process. Confronting people with norms, does not necessarily mean that afterwards one is behaving more according to the norm. Some studies even indicate that social-norm marketing campaigns have increased the undesirable behaviours and misperceptions they set out to decrease. This is called the 'boomerang effect'. The success of a descriptive normative intervention depends on how people perform compared with the rest of the group. If someone performs less good compared to the average, he tends to improve his future behaviour, after he is confronted with a descriptive norm. However, when one performs better compared to the average, he tends to perform less good in the future. The addition of a injunctive normative intervention (i.e. the (dis)approval of the behaviour) eliminates this undesired boomerang effect (Schultz, Nolan, Cialdini, Goldstein & Griskevicius, 2007). A injunctive normative intervention can be a very simple message, e.g. in the form of a smiley face.

Appendix D

The prospect theory

Amos Tversky and Daniel Kahneman have done very important research to the discrepancy between normative decision models and actual behaviour[1]. They proposed that the deviations from normative behaviour are systematic, causing humans to deviate from their rational principles (1972). Furthermore, they argue that people make decisions using all kinds of heuristics, possibly leading to several types of biases and errors (Kahneman et al., 1982). In their own words, these heuristic principles "reduce the complex tasks of assessing probabilities and predicting values to simpler judgmental operations. In general, these heuristics are quite useful, but sometimes they lead to severe and systematic errors" (Tversky & Kahneman, 1974, p. 1124).

Tversky and Kahneman described three heuristics, labelled the availability, the representativeness, and the anchoring and adjustment heuristic. When people use the availability heuristic, they base a judgement on the ease with which they can bring something to mind. This happens, for example, when someone is recently confronted with a similar incident or because it is easy to bring it into mind given some remarkable details. When the representativeness heuristic is used, people classify something according to how similar it is to a typical case. Thereby they tend to ignore the base rate information, i.e. the information about the relative frequency of members of the category in the population. The anchoring and adjustment heuristic entails the insufficient adjustment from a number or value (the anchor) that is used as starting point.

With the formalization of prospect theory, Tversky and Kahneman (1979) tried to implement their research to heuristics and biases into a descriptive decision making model. The prospect theory can be considered as a modification of the expected utility theory. It states that the prospect (V) is determined by the product of a an outcome and a decision weight. The outcome is not equal to the objective outcome, but is determined by a specific type of value function $(v(x_i))$. Furthermore, the decision weight is determined by a function of the objective probability $(w(p_i))$. The Equation can be found below.

$$V = \sum_{i=1}^{m} w(p_i)v(x_i). \tag{D.1}$$

Later, Tversky and Kahneman extended this theory to the cumulative prospect theory to overcome some technical problems (Tversky & Kahneman, 1992). This extension is generally seen as a major improvement to the prospect theory. Therefore, only the cumulative prospect theory will be further discussed here. Both theories posit "that individuals evaluate outcomes with respect to deviations from a reference point rather than with respect to net asset levels, that their identification of this reference point is

[1] This appendix is a part adapted from Van Os (2011a)

a critical variable, that they give more weight to losses than to comparable gains, and that they are generally risk-averse with respect to gains and risk-acceptant with respect to losses" (Levy, 1992, p. 171). All these features are reflected in the value function. This function is typically S-shaped, and is steeper for gains than for losses. Experimental evidence shows that this ratio is about 2:1 (Tversky & Kahneman, 1991). The value function $v(x_i)$ can be described as a two-part power function, for $\alpha, \beta \in (0, 1)$ and $\lambda > 1$, of the form

$$v(x_i) = \begin{cases} (x_i)^\alpha & \text{if } x_i \geq 0, \\ -\lambda(-x_i)^\beta & \text{if } x_i < 0. \end{cases} \tag{D.2}$$

Furthermore, the theory contains a weighting function $w(p)$ that transforms objective probabilities into subjective probabilities, in such a way that small probabilities are underweighted, and that moderate to large probabilities are overweighted (Rieger & Wang, 2006). Typically, this probability weighting function is S-shaped (first concave, then convex) and regressive. Furthermore, it is asymmetrical, with a fixed point at about $1/3$, and reflective (Prelec, 1998). In his research, Prelec proposes a probability weighting function that meets these characteristics and is supported by experimental evidence (see Equation 5). Although often used, some authors suggest other probability weighting functions (Rieger & Wang, 2006).

$$e^{-(-\ln p)^\gamma)} \qquad 0 < \gamma < 1. \tag{D.3}$$

The general Equation, derived from Fennema and Wakker (1997) for the cumulative prospect theory will be

$$V = \sum_{i=1}^{m} \pi_i^- v(x_i) + \sum_{i=m+1}^{n} \pi_i^+ v(x_i). \tag{D.4}$$

where the decision weights (i.e. the numbers π_i^-, π_i^+) are defined by:

$\pi_1^- = w^-(p_1), \qquad \pi_i^- = w^-(p_1 + \ldots + p_i) - w^-(p_1 + \ldots + p_{i-1}) \qquad 2 \leq i \leq m,$

$\pi_n^+ = w^+(p_n), \qquad \pi_i^+ = w^+(p_i + \ldots + p_n) - w^+(p_{i+1} + \ldots + p_n) \qquad m + 1 \leq i \leq n - 1$