The social cognitive actor

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CHAPTER 7

Discussion and Conclusions

In this chapter, we want first of all refresh the mind of the reader and explain what we think is important to be addressed in the discussion of the dissertation. For this, we will refer back to the previous chapters and especially chapter 1 that gave the direction for the research path that has been followed throughout this dissertation.

The purpose of the dissertation is to remove the blinkers from both cognitive science and social or organisational science. The dissertation made explicit that behaviour of human beings cannot solely be understood by cognitive or social science alone, i.e. this research states that the actions of the actor depend on both, the cognitive and the social or organisational context of the actor.

Secondly, we want to raise a couple of new questions; questions concerning our cognitive actor RBot, the construction of the virtual world in which they live (MRS) and the position our cognitive actor RBot takes in the cognitive and social simulation community.

The previous point addresses the need for new development and further research. This chapter will end with a section that addresses areas of research in which RBot as a cognitive agent-based social simulation toolkit can be applied and what remaining work needs to be done.

7.1 Research findings

In chapter 1, our questions guided us along a road starting from Multi-Agent Systems towards the social and cognitive actor that resulted in our new cognitive agent-based social simulation toolkit that consists of RBot and MRS.

The main research question was to investigate what the aspects of actors are that plausibly can explain social interactive behaviour. We tried to tackle this question by adopting the view of methodological individualism that states that all social phenomena are purely based on cognitive processes of individual agents. The Multi-Agent System (MAS) methodology and techniques we adopted and explained in chapter 2 fit adequately for solving our research question. However, MAS concentrates predominantly on coordination mechanisms, emergence of behaviour and interaction between agents. Although it applies the individual actor as core unit of its methodology, most applications in the field of MAS are not that concerned with the cognitive plausibility of agents.

The notion of strong agency as applied in MAS made clear that most agents are described and implemented at the rational level of description. A description at the intentional (or rational) level assumes rational behaviour according to economic theory and perhaps boundedly rational actor behaviour. It does not take into account the functional level (see chapter 4) that incorporates cognitive mechanisms and functions that allow for better modelling of individual cognition based on which better aggregate models of social behaviour can be developed.

On the other hand, although studies that concern social cognition already exist for some time (e.g. Suchman, 1987; Vera & Simon, 1993), computational models of cognition up till now have often neglected social, organisational and cultural processes. When we develop models that attempt to explain social interactive behaviour, we need to take into account the cognitive plausibility of the actor for a better understanding of the origins of social behaviour. And when we model a cognitive actor that is able to exhibit social behaviour, we should also take into account two types of knowledge:

> One kind comes from individual sources and the other from social sources. This dichotomy may be somewhat simplistic, but the contrast between the two kinds should prove to be important. The individual sources are made up of learning processes involving an agent's interaction with its environment (both sociocultural and physical) and the resulting (implicit or explicit) representations. The other kind of knowledge involves social sources, which results from concepts and conventions formed in broader contexts and is somehow imposed on (or even "forced upon") individuals. (Sun, 2002, p. 192)

In chapter 3, we introduced the concept of social construct, an explicit (and possible implicit) representation that allows for modelling emerging and existing conventions in formal and informal organisational settings, i.e. the social construct is a knowledge entity or representation that connects the individual actor with the social world and the other way around.

In chapter 5, we created a design of the social cognitive actor RBot equipped with a cognitive architecture based on ACT-R. Next, we created a task environment (MRS) in which multiple actors can perceive and interact with each other. We also implemented the social construct at the meta-cognitive or normative level of the individual actor, enabling the actor to remember and exchange social constructs applicable to certain situations, i.e. the actor has a separate habitual or situational memory.

Compared to the distinction between social and individual sources of knowledge, we do not want to create such a sharp line between social and individual sources of knowledge. At the end, any social source of knowledge becomes an individual source of knowledge, the moment the actor understands and uses the social source of knowledge. There is always an opportunity for our RBot actor to forget or change the representation of social constructs before sharing it again with the rest of its community. Although we think that the difference is not that strict, we agree with Sun in the sense that a social construct (as a source) can have impact on implicit or explicit knowledge stored in the memory of the actor, while personal knowledge in the memory of the actor may turn into a social construct by processes of communication and negotiation.

We state that this research, and especially the concept of social construct, can contribute to cognitive science as well as the social and organisational sciences.

Cognitive science In case of cognitive science, the social construct as a knowledge construction and representation in the mind of the individual allows cognitive scientists to model social phenomena such as norms, coordination mechanisms and other types of plans that exist both in the mind of the actor and as social artefacts (e.g. signs formalised on paper) in the outside world (semiotic Umwelt).

Social and organisational sciences The social and organisational sciences aim at explaining organisational behaviour based on informal as well as formal coordination mechanisms and social structures, assuming that a behaviouristic approach of individuals is sufficient. However, the social and organisational sciences deserve a better grounding based on more sophisticated theories explaining the behaviours of individual humans. In our opinion, social constructs embedded in cognitive plausible actors can be a promising start for understanding the connection between individually constructed behaviour and socially constructed behaviour.

In the remainder of our research findings, we want first to discuss the theoretical research questions as we posed in chapter 1.

1 What are the aspects of actors that plausibly explain interactive (social) behaviour?

1.1 What type of a model can explain interactive (social) behaviour?

1.2 What is required for an actor to exhibit (stable) social behaviour?

1.3 What kind of an actor can plausibly handle signs, relations and social constructs?

These questions are primarily answered in chapters 2, 3 and 4. Based on those chapters, we will elaborate the theoretical conclusions we have drawn.

Secondly, we want to discuss the conclusions regarding the implementation of our cognitive and social actor RBot and the environment MRS that allows for multi-actor simulations. In chapter 1, we gave a set of implementation questions that addressed the working of the new cognitive architecture RBot based on which we can draw conclusions regarding the applicability or usefulness of RBot (primarily answered in chapter 5 and 6). The questions concern the validation of RBot as a cognitive plausible actor and the working or demonstration of RBot combined with MRS as a successful instrument for studying and explaining interactive social behaviour.

2 How can (cognitive and social) plausible actors be implemented in a Multi-Agent System?

2.1 Is RBot comparable to ACT-R as a valid cognitive plausible actor?

2.2 Is it possible that social constructs and organisational behaviour can emerge from social interaction?

2.3 Is a social construct a coordination mechanism that can influence the behaviour of related actors that interact towards a certain desired behaviour?

In the next sections, section 7.1.1 and section 7.1.2, we will address the theoretical conclusions, and the implementation and experimental conclusions, respectively.

7.1.1 Theoretical conclusions

In our research, we are concerned with the constructive aspects of the individual and how those aspects, in interaction with others, result in (stable) social behaviour. We stated that there are many levels of description, varying from physical towards the social level of description. The main research question gives the incentive not only to look at the social level, i.e. what causes actors to be social and interact social, but also the relations or connections between the social level and other levels of description. More specifically: what aspects of the individual cause actors to behave social; and the other way around, how does social behaviour of actors influence the individual actor.

In other words, we are convinced that in order to explain social behaviour, a more constructive analysis of the individual (e.g. the intentional and functional level of description) is necessary to understand behaviour that emerges from interaction between individuals. This so-called methodological individualism is necessary to understand the implications individual behaviour has on organisational and social behaviour.

The theoretical question 1.1 addresses methodological individualism and multi-agent based simulation methodology also known as Multi-Agent Systems (MAS). We explained techniques commonly used in MAS and explained the constructive engineering methods or views that are applied to implement agent models. We concluded that most techniques are at the intentional level of description in explaining the behaviour of the individual. In our research, we want a more functional approach (the functional level) in modelling the behaviour of the individual. We prefer to use a cognitive architecture with functional descriptions of different components and cognitive mechanisms that are empirically validated based on research and experiences in the field of cognitive psychology. Hence, our conclusion is that MAS is an appropriate methodology, however its agents need to be cognitive plausible in order to mimic individual (and social) behaviour as accurate as possible. We will come back to cognitive plausibility in question 1.3. We first want to discuss social behaviour and MAS, i.e. the theoretical question 1.2.

In chapter 3, we asked ourselves what is required for an actor to exhibit social (stable) behaviour. For an actor to understand the needs of others, it has to have the ability to place itself in the other, i.e. it has to be able to represent the other in its own mind in order to reason about the other's goals, beliefs etc. We adopted social constructivism as a theory that allows for explaining social behaviour in the perspective of the individual as well as the perspective of society.

We argued that organisations exist primarily in the mind of individuals (an organisation is ontologically subjective, see chapter 3). We are in need of such a strong notion because (1) we adopt methodological individualism and (2) in order for individuals to reason about social structures and behaviour, we argue that this is only possible when they are represented in the mind of individuals.

In the second place, we argue that actors live in a semiotic Umwelt that allows the actor to process, use and transfer signs. A semiotic Umwelt enables the actors to exchange signs or signals and construct an internal representation of that world (the Innenwelt). In order to make sense of signs (semiosis), support of a communication process is necessary for actors in order to (socially) interact with each other. Apart from that, we also argued that a communication process presupposes a signification system; a system that allows actors to make sense of signs received from the environment, and is necessary to produce meaningful signs to act upon that world.

The signification system allows the actor to become physically and socially situated in its environment. The physical situatedness is based on physical affordances and the experience of the individual with the physical world. On the other hand, social situatedness depends upon social affordances as representations in the mind. Those representations are social behaviour patterns that emerged out of interactions with individuals and have a clear distinctive normative character[1].

In our work, we used the concept of a social construct. A social construct is based on social affordances and can be seen as a representation of cooperation and coordination. A social construct is a relatively persistent socially shared unit of knowledge reinforced in its existence by its frequent use.

Hence, when we want to interact with the world, we have to socially construct that world in order to give meaning, as a community, to that (social) world. The social construction of the (social) world results into *external* and *internal* representations of social constructs. The individual holds the meaning of agreements, objects and so on in its mind, but on the other hand, many objects in the physical world have a social meaning as well when there are social constructs attached to them that are shared within a community. Therefore, we conclude that social constructs are represented (as signs or symbols) not only in the mind but also as signs, social (and physical) affordances in a world (the

[1] Some argue that everything is socially constructed. The interactions with (physical situated) objects are learnt by imitating (e.g. child-play) others, or being taught by others (e.g. driving a car).

semiotic Umwelt) that is socially constructed and agreed upon, based on meaningful interactions (semiosis) between individuals.

Thus, a signification system allows us to interact with the environment and exchange social constructs with other actors. However, in order for the actor to hold and manipulate signs using a signification system, the actor requires a system that can handle those signs and represent a signification system.

Research question 1.3 and chapter 4 address the need for a cognitive plausible actor that is capable of handling signs and social constructs. We introduced the cognitive architecture or physical symbol system because it allows us to model a cognitive plausible actor, which is able to hold representations (signs, social constructs) and to process or operate on those representations.

In chapter 4, we elaborated the differences between the classical approach (GOFAI), connectionism and embodied or situated cognition in cognitive science. In our search for a suitable cognitive architecture that can serve as a model for the cognitive actor, we made a comparison between the two most promising architectures in cognitive science today, i.e. ACT-R and SOAR. We took the decision to adopt ACT-R, mainly because of its sub-symbolic activation that resembles and allows to model connectionist-like networks. Apart from that, we argue that ACT-R has some shortcomings.

The first one is its lack of interaction with the environment, i.e. its physical and social situatedness is lacking. Therefore, we need to adopt embodied cognition and more specifically the principles of the subsumption architecture and a physical (or spatial) memory that enables the cognitive actor to be physically situated and react instantaneously to changes in the environment. We adopted a similar mechanism for making the actor socially situated in its environment by creating representations in the form of social constructs that make the actor aware of certain situations that trigger the (now social) actor to change its goals, actions, and so on.

The second shortcoming of ACT-R is that its focus is not on the implementation of a task environment in which more actors can interact with each other. Therefore, ACT-R's communication apparatus to exchange language and interact with other actors still has shortcomings (The ACT-R community, 2005)[2].

ACT-R is a sophisticated example of the classical approach in cognitive science. We concluded that in order to make ACT-R work as an architecture that also can explain social interactive behaviour, we have to come with a complete redesign of ACT-R software[3]. The new design is named RBot (programmed in JAVA) and follows the ACT-R theory closely, except for a few innovations. Apart from the actor redesign, we created a model of a task environment (Multi-RBot System: MRS) that should enable designers to model experiments with multiple actors interacting in a simulated physical and semiotic environment.

Summarised, we can conclude that in this dissertation we addressed 1. the usefulness of MAS models to model social interaction (research question 1.1), 2. that social constructs are necessary for actors to exhibit social behaviour (re-

[2]From a conversation with one of the developers of ACT-R (Niels Taatgen) we received this report.

[3]The ACT-R community discovered in version 5.0 that their model required a redesign into a more modular approach.

search question 1.2), and 3. that actors should be equipped with a cognitive architecture to handle representations such as social constructs (research question 1.3).

In the following section, we will elaborate the conclusions regarding the implementation and demonstrative experiments concerning the capability of RBot to explain interactive social behaviour.

7.1.2 Implementation and experimental conclusions

The first implementation question concerns the implementation of (1) a cognitive and (2) a social actor in a (3) task environment; an environment in which actors can interact and exchange knowledge. Before going into details about the experiments we conducted, we first want to shed some light on the problems we encountered with ACT-R when we tried to implement experiments in a multi-actor environment.

Implementation

The first problem (ACT-R version 4.0 and 5.0) was its inaccessibility regarding its API[4] and modularity of design[5] (in terms of software engineering). Besides the software issues concerning the design of ACT-R, we had to implement the social aspects (constructs) and a multi-actor environment as well. The combination of those aspects made us decide to create a complete new software model called RBot. RBot inherited as much as possible the characteristics of the theories of ACT-R, i.e. the cognitive part of the design is comparable to that of ACT-R. However, there are some shortcomings in ACT-R as stated by an internal report of the ACT-R community (The ACT-R community, 2005, p. 1):

> . . . there are still significant holes in the ACT-R architecture that reflect its origins in the set of tasks that cognitive psychology has focused for purposes of experimental control—tasks that are typically routine, repetitive, and dispassionate. The architecture has difficulties in domains that emphasize metacognitive processing, strong emotions, and communication.

Besides that, we also conclude that other aspects—social aspects and multi-actor task environment—are not present in ACT-R and therefore require new mechanisms or representations to implement them.

In the design chapter, chapter 5, we drew the conclusion that we addressed the following in this dissertation: the meta-cognitive processing, the implementation of social constructs, and the communication (interaction between multiple actors). Strong emotions are for further research to be implemented, but we assume they can be implemented in a similar way as meta-cognitive processes.

Concerning the design of a cognitive architecture, we made a redesign and created the following (cognitive) innovations in RBot compared to ACT-R. The

[4] Application Program Interface

[5] ACT-R version 6.0 is a redesign of version 5.0 and was created for a better modular approach. However, this new version was released after we already redesigned ACT-R.

first innovation is the introduction of a generalised memory architecture consisting of chunks, links, and memorymaps (access structures) enabling a modular architecture and allowing a simplified modelling of complex semantic network structures compared to ACT-R. Another change is the ability to express productions as networks of chunks that allow for a better management and component reuse. The extension concerning meta-cognitive processing is the addition of social constructs as an architectural module (memorymap plus handler) to the memory of RBot. The social construct allows for interruption of normal problem solving and links external (social and physical) events to internal reasoning.

However, to be socially and physically situated, the actor requires a task environment in which it can live or better, a 'semiotic Umwelt' in which it can interpret and exchange signs. The semiotic Umwelt requires the actor to have a signification system or communication (language) module that allows the actor to exchange signs with other actors and the environment. RBot is equipped with two memorymaps that take care of the interpretation of signs from the outside world. The first memorymap is the physical (or spatial) memorymap that allows the actor to synchronise its (self-represented) position with the outside world and other actors. The other memorymap is the social construct memorymap that holds social constructs containing norms that are applicable to situations in the environment.

The capability of the actor to perceive an environment brings forth the need for a separate module that represents a virtual world in which actors can live, i.e. interaction between actors requires a simulated representation of reality; a virtual and semiotic world in which actors can exchange and make sense of each other and objects that are present in that world.

For our cognitive multi-actor simulation to work, we can now conclude that the following components are necessary to simulate a task environment in which actors are physically and socially situated:

A cognitive plausible architecture A cognitive plausible architecture or physical symbol system allows the actor to perceive and remember symbolic representations, and decide and act upon those representations. Because of its memory, the actor is able to learn from its experiences and adapt its behaviour successfully in a flexible way conform to the changes that are perceived from the environment.

A semiotic Umwelt A semiotic Umwelt or a (multi-actor) task environment in which the actor can live and interpret, produce or exchange signs with other actors and with its task environment. The physical environment is linked to the semiotic Umwelt, but only perceivable by the actor (mediated by the semiotic Umwelt). The first task of the semiotic Umwelt is to offer the actor signs that represent the physical environment to the actor. Secondly, the semiotic Umwelt is a precondition for the actor to be able to communicate, use language and behave socially by exchanging meaningful messages to other actors.

Social constructs/meta-cognition Social constructs and a subsumption mechanism (as discussed in chapter 5) allow for representation of norms, representations of social structures and representations of other actors. The social construct allows the actor to be socially situated, respond to social events and include the social needs of other actors with whom the actor interacts.

These components are integrated in one combined software package consisting of the task environment MRS (Multi-RBot System) and the cognitive actor RBot. The following section explains the experiments that demonstrate some of the capabilities of RBot and MRS.

Demonstrative experiments

The first experiment we conducted compared the behaviour of RBot (component 1) with the behaviour of ACT-R. The simple addition-problem experiment demonstrated a couple of characteristics present both in RBot and ACT-R. Among them are the working of the goal stack, the flow of procedures, the learning of experiences regarding procedure execution, the base-level learning equation and the merging of chunks. We are aware of the fact that a more complete testing of RBot might be necessary, but the aim of our current research is not to do cognitive tests regarding the (precise) cognitive plausibility of RBot. Because RBot follows ACT-R closely (except for the enhanced capabilities mentioned above), it is assumed that it inherits the cognitive plausibility of ACT-R. Our purpose of the experiment is to show the way RBot handles its problem space by applying procedures that are executed based on goal-directed behaviour, similar to the way goals are handled in SOAR and ACT-R. Based on the many debugging cycles and experimentation of many functionalities in ACT-R, we can conclude that we developed a cognitive plausible architecture for our research aim. RBot is adequate and accurate enough for accomplishing our goal: the development of a simulation toolkit with plausible cognitive actors that enables us to explain social interactive behaviour.

The second experiment focuses on the construction of the semiotic Umwelt and task environment that allows the actors to perceive and interact with other actors. Based on the results of the experiment, we can conclude that the actors have the capability to adapt their behaviour based on experiences with other actors, i.e. when we inspect the sub-symbolic properties (intra-individual level) of the actor, we notice that the behaviour of the actor adapts itself to the behaviour of the other actor (its environment). Another aspect we noticed is that actors based on their repeated experiences with each other start to produce repetitive, predictable actions or habits.

These habits occur because the actors make use of their (reinforcement) learning capabilities that allow them to experience from the past what will (with a high likelihood) be successful behaviour when the situation repeats itself again. Repetitive or habitual actions are the basis for the emergence of social constructs. A similar kind of learning takes place in the explanation of skill development as discussed by Anderson (1982). ACT-R's initial skill development takes place by acquiring declarative knowledge. After this stage, through practise, procedures emerge that perform the task without the acquired declarative knowledge, resulting in faster execution of problem solving.

Therefore, in the case of our experiment, we can conclude, that the reinforcement of specific productions in social interaction situations is a kind of skill mechanism. Because of its repetitive nature, actors develop skills to adapt and select the correct choice when certain situations repeat themselves often. The habitual behaviour that is produced by actors is behaviour that is constructed and caused by interaction between actors. Besides the interpretation of the habitual behaviour of the individuals and their interaction, we can conclude that the task environment MRS and the perception of RBot are working adequately and enable us to create models of cognitive actors that perceive each other and are able to learn from their interactions (previous mentioned component 2).

Whereas the second experiment produced coordinated interactive behaviour based on individual adaptation to the environment (the other actor), the third experiment implements a (formal) social construct as part of a meta-cognitive process that allows actors to react immediately on a social situation and thus influence each other's behaviour. The experiment shows that social constructs have impact on the behaviour of the actor; in the case of this experiment, the utility of a procedure. Based on the results of this experiment, we can conclude that one actor is able to influence the behaviour of the other actor *intentionally* by sending a social construct message to the other actor. The strong point of RBot is that besides modelling declarative and procedural knowledge, i.e. what facts the actor knows and what the actor is capable to do, it is possible to model normative knowledge in the form of social constructs that says something about what the actor is capable to know or allowed to do according the rules or norms of a community in which the actor takes part. In our experiment, we see this normative behaviour when the actor that has to obey the policeman, makes an attempt to break the rules of the policeman. After receiving a normative message (a social construct) from the policeman that corrects the wrong doing of the disobeying actor, the transgressing actor immediately alters its behaviour. This is not the result of an imperative force, but of its action preferences that shifted instantly. If the preferred action cannot take place, its activation will diminish and, in due time, other action possibilities may become preferred again. Therefore, the implementation of social constructs not as imperative command but as a meta-cognitive capability has proven itself to be successful in this experiment

We argue, based on the theoretical, implementation and experimental questions that RBot and MRS are useful for modelling cognitive agent-based social simulations. In our experience with developing models and experiments for RBot we can conclude that the developed model is relatively easy to maintain and to understand due to its modular/component based design. In the next section we want to discuss a couple of new questions that will challenge us in the further development of RBot.

7.2 New questions raised

In this dissertation, we are interested in developing a computerised model that can explain social behaviour that results from interacting cognitive plausible actors. In this section, we want to raise a couple of questions that concern our architecture or model; questions that should guide us to new developments, comparison with already existing work and further work (which is discussed in the next section). We will divide this section into three parts: (1) the cognitive RBot actor, (2) the task environment or semiotic Umwelt (MRS), and (3) questions concerning the applicability of RBot and MRS.

7.2.1 Questions concerning RBot

In case of our cognitive actor, we can raise the question of how accurate and cognitive plausible our RBot model should be. Many AI researchers are dealing with the performance and cognitive plausibility of the simulated individual in how it interacts with its environment and learns from prior knowledge (and acquired new knowledge). Experiments in cognitive psychology concerning a single individual are often conducted in a laboratory setting under controlled conditions. In our research we are especially interested in the relation between and modelling of cognitive plausibility and social plausible behaviour; a relation that is often neglected by both cognitive and social scientists (see Sun, 2006a; Conte & Castelfranchi, 1995b). Although the aim of RBot is not to become a full-fledged cognitive architecture and serve as an instrument in cognitive experiments, we strive for an as cognitive plausible actor as possible. Hence, we should ask ourselves questions regarding the cognitive mechanisms and components we want to implement in RBot and whether those questions could add to the social plausibility of the behaviour our cognitive actor will produce. The questions we are interested in are questions concerning the functional primitives and cognitive mechanisms of the individual's mind, and specifically those questions that can possibly explain social behaviour. As mentioned before, the mind can be divided in several functional parts or primitives[6] as follows:

Memory (types of memory) What types of memory (declarative: semantic, episodic, categorical or non-declarative: procedural (skill/habit), perceptual, emotional, spatial, short-term/long term, relational) are fruitful to be implemented in RBot in order to let RBot become even more cognitive and social plausible.

Memory processes and learning RBot already inherited several memory processes (base-level learning, merging) from ACT-R. However, apart from those processes, could it be useful to implement top-down learning ("proceduralization") or bottom-up learning (see Sun, 2001), because our experiments have shown that such mechanisms might be active in situational or social learning (habituation) as well?

Executive processes RBot relies on its social, task and physical context when it wants to execute an action. Most actions, connected to productions, are given as prior knowledge to the actor. Concerning the actions of RBot, we could ask ourselves whether we need more advanced planning modules that allow for a more structured way of planning. With help of introspection, RBot cannot only learn from its productions, it can also learn from

[6] We apply here the primitives as stated in the Proposer Information Pamphlet of the BICA program. Retrieved 18-06-2006: http://www.darpa.mil/ipto/solicitations/open/05-18_PIPPrint.htm.

its plans that are a combination of productions and relevant knowledge and (context) constraints that are necessary to fulfil tasks. Moreover, we have to think about questions that concern social plans; plans that depend on social constraints and are socially constructed by a group of interacting individuals.

Language/Symbolic communication The language or communication possibilities of RBot allow for the transportation of symbols and structured knowledge, such as goals, procedures, social constructs and so on. The development of language skills is not worked out in RBot, but we are aware that language development during discourse between actors is important for establishing agreements and social constructs between actors. We acknowledge the important work being done in cognitive science concerning language generation and the acquisition of language skills. However, we think that we should consider questions concerning language action, i.e. what is the contribution of language concerning coordination, its effect on emotions and other mechanisms or values of actors that influence social behaviour between actors.

Emotions Emotions can be considered as a cognitive moderator or as a separate module that controls emotions. Research has been carried out on emotions of the individual (see Breazeal & Brooks, 2004; Sloman, 1987; Wright et al., 1996), but there has been little progress in this area. Some questions that are concerned with emotions could become important for our research when emotions are used for communicating social needs (e.g. with help of an 'emotional' language that has meaning for a group of individuals) that can contribute to coordination and social behaviour.

Knowledge representation/logic and reasoning Knowledge can be represented in the mind as symbols, a set of knowledge chunks, inferences (logic), rules, scripts, neural networks, as implicit or explicit knowledge, and so on (cf. Anderson, 1984, pp. 2–3). RBot makes use of representations in the form of chunks and its reasoning is rule-based and not so much on logics. ACT-R and RBot, due to their sub-symbolic properties, are so-called hybrid architectures. We are interested in questions concerning how social knowledge is represented in the individual mind, especially knowledge about social structures and constructs that are shared by a group of actors.

Motivation and goals Right now, RBot's goals are given as prior knowledge and its motivation for solving those goals depends largely on the initial parameters it receives for the amount of time it can spend on a goal and the costs associated with fulfilling that goal. The generation and formation of goal structures and associated plans are not developed for RBot. Besides that, RBot (similar to ACT-R) has not a motivational (meta-cognitive) subsystem that maps the (internal and (social) external) motives of the actor to goals, plans or procedures, or other sub-symbolic properties. However, RBot has a meta-cognitive processing system that can be applied to create a motivational subsystem that works in parallel with the recognise-decide-act cycle and thereby can influence that cycle.

Remaining components The remaining questions concern components that are concerned with perceiving the outside world. Because these components are closely linked to the environment in which the actor lives, we will discuss perception in the next section.

7.2.2 Questions concerning MRS

MRS (Multi-RBot System) is a task environment or semiotic Umwelt that defines what signs can be perceived by actors, i.e. the environment delivers services to the actors, such as the synchronisation of time, notification of physical objects and other actors, and a communication platform allowing actors to exchange knowledge with each other. The second service or function of the environment is its graphical presentation to the researcher looking at his screen and delivering information concerning the behaviour of the actors on the screen. About both these subjects, we formulate questions that concern those services:

Service of the environment to its actors

Currently, the actor takes a passive role in perceiving its environment; the environment notifies the actor, the moment the server decides something is in perceptual range of the sensors of the actor. The question is whether a clever pro-active attention mechanisms should be implemented to make the actor less dependent from its environment.

Another question concerns the client-server patterns that we applied in our software architecture; it creates a dependency between actors and environment. We have to make a distinction between the server as communication facility between the actors and as substitute for a physical environment. In case there is no need for a simulated physical environment (because the actors live in a real physical environment or a 'real' virtual world like Internet), we see that the dependency on a single server as communication medium leads to brittleness of the multi-actor system. The moment the server fails, the clients become blind, deaf and silent (they can scream but there is no medium to transport their signs). This dependency prevents actors to act as a complete autonomous entity. The question is whether we should implement a Peer-to-Peer (PtP) pattern allowing actors to be a client and at the same time take the role of a server[7]. In the case of our experiments, central control gives an advantage by having direct control over the activities of actors. However, there are cases in which the PtP solution could be a better alternative. As an example, we can think of (1) the case in which robots equipped with RBot are being sent to an environment such as high risk environments (the Moon, Mars, volcano's, deep ocean) and we cannot afford the risk by having a single point of failure; (2) another case would be a huge amount of actors that want to communicate with the server. In that case, either more servers are required, or responsibility and more autonomy have to be given to the actor.We estimate that the modular design allows for a relatively simple extension of

[7] In a PtP environment, we can expect actors (when they are cooperative) to share their environmental experiences, thereby fulfilling the task of the server.

RBot (capable of acting in a PtP infrastructure) thereby becoming less dependent on the environment delivered by the server.

Service to the researcher in the form of data and graphical presentation
The current version of MRS allows to present graphs from a database that stores data generated by every actor in the simulation environment. The interface provides the graphical presentation of events or experiences during the actors lifetime, and the plots that present movement of both actors in a two dimensional field. The other type of presentation is a dynamic view of the movement of actors displayed on a 2D grid (operational graphics). In the case of the presentation to the researcher, we can wonder how important a more sophisticated environment will be for our research purposes. When we are concerned with the impact of buildings or other structures on the social behaviour of actors, then we should pay attention to a possible 3D presentation of the environment; a change of presentation of the environment which will probably not cause much change in the underlying software model. We will come back to this issue in the section that discusses further work.

Many more questions can be brought forward that address the design of RBot and MRS. Although these questions seem unnecessary without a good plan, we argue that they can give incentives to create new research ideas and provide us with the possibilities in what directions we can develop our current architecture and environment. These directions depend primarily on our decisions we will take in our further work and the type of applications or research we have in mind that can be supported by our toolkit.

7.2.3 Questions concerning simulation and application

As we already mentioned in chapter 6, we suggest that our toolkit can be applied in different types of research: (1) research concerning the further development of a toolkit that support (2) research that is interested in a specific social or cognitive situation (e.g. simulation of crowd behaviour, simulation of cooperation in a scientific research project, simulation of workflows, simulation of multi-actor planning and coordination). Although other types of applications fall outside the category of studying human behaviour, they are closely connected to our research. We can think of (1) (personal) software agents on the Internet, (2) robots that have to interact in a group or (3) applications in the game industry.

We argue that our simulation toolkit requires further development and that many more tests are necessary to validate the behaviour of our toolkit. In the first place, our research aims at explaining interactive social behaviour (based on cognitive plausible actors). Therefore questions that concern the application of simulation in our research should be combined with empirical research in the fields of cognitive, social and organisational science for a better understanding of human (social) behaviour. In the next section, that discusses further work, we will discuss what the next phase of our research will involve.

7.3 Further work

There are many possibilities to continue our research. Partly caused by the multi- (or inter-) disciplinary and complex nature of cognitive agent-based social simulation, which has its roots in many areas as the reader probably discovered in this dissertation. We do not want to elaborate too much about all the options and ideas for further work that are possible with a model as RBot. Our discussion will limit itself to the current ideas for the short term. There are two research projects with which we want to continue our research. The first project concerns the modelling of crowd behaviour (see Still, 2000). The second project concerns the effect of design of buildings on behaviour of groups/individual behaviour (see Mobach, 2005).

Crowd behaviour

Urbanisation and the exponential growth of our world population are the cause of dense concentrations of people. Apart from that, events such as a soccer game or demonstrations cause the cluttering of huge amounts of people. Today, there has been some progress in the management and control of crowd behaviour, but there still remain many questions unanswered; especially questions about when and why certain crowd behaviours escalate into riots and others not.

The behaviour of large crowds is often controlled by police forces or the army. Crowds are most of the time unorganised entities, in the sense that they do not have (formal) organisational structures. On the other hand, the police force or army is often formally organised into strict hierarchical structures. There are numerous of agent-based social simulation models that describe and attempt to predict crowd behaviour at a high level of description by creating a behaviouristic (stimulus-response) model based on a simplified model of the individual agent. These models (e.g. Swarm[8]) are successful in describing group behaviour and they resulted in models that give a good approximation of how people behave when they are all similar and imitate each other's behaviour.

However, when we study soccer riots, we know that at least one group is organised. In this case, the police as a group has a formal organisation and therefore behaves 'organised'. Because there is a clear difference between the crowd and the police in the way they are organised, we argue that there also should be a difference in the way they behave.

Whereas the crowd is probably impulsive and reacts on unexpected situations that can occur during crowd behaviour, the police men are trained and organised and have clear instructions how to deal with certain situations. Therefore, we can state that there is a difference in rules (of the game) and social structures between the crowd and the police force.

Many researchers define differences between individuals (agents) of these groups by giving the two groups each different attributes or rules. In our opinion, such an approach is correct when there is no need for studying the individual. However, in the case of training police officers to be part in preventing or

[8] See http://www.swarm.org/wiki/Main_Page.

controlling a riot, the behaviour of the individual according to scripts, plans and norms needs to be modelled as well.

The research conducted in this dissertation can contribute to give a better understanding and prediction of behaviour of individuals in crowds, i.e. further work concerning simulations in the domain of crowd behaviour is an aim of the near future. As a side effect, such a challenge can prove if our model can be scaled up towards a simulation that consists of many, maybe thousands of agents.

3D Organisation Science: design based on simulating behaviour of human agents

The introduction of modelling buildings in 3D virtual reality starts to pay off as a serious step in the design process of a building. The construction of buildings with help of computer graphics today becomes more and more affordable for companies with small budgets. Models that are developed with help of computers (Computer Aided Design) have found its way to almost any company that is occupied with construction projects. After the introduction of 2D CAD models, followed up by 3D (2½D) models, 3D environments in which people can see projections of 3D models are the next step.

Besides the 3D projection of buildings, architects are interested in what the impact of a building is on the behaviour of the individual as well as the behaviour of the building on groups of individuals. For the purpose of this project, it is an advantage that our research project already integrated physical affordances as a mechanism in the actor. Besides that, social constructs are modelled as well, which can provide for a better understanding of social behaviour. With help of affordances and social constructs, we are able to model actors with different characters that respond in various ways to the design of for instance corridors, light fall through windows and so on.

Hence, most multi-agent software that already exists for 3D simulations are concerned with the way the actors respond to the environment; the agents are behaviour and environment (situation) oriented similar to the embodied and situated cognition approach. What is missing in this type of simulation agents is cognition, a cognitive architecture that makes an agent more pro-active and autonomous, i.e. it transforms the agent into a cognitive plausible actor. RBot provides a cognitive architecture that enriches the reactive agents in the 3D simulations.

Whereas the focus in 3D simulations is often concentrated on graphics and the projection of the 3D environment, in RBot (and MRS), the focus is on cognition and social interaction. Clearly, there is a benefit for both parties: the 3D simulations takes advantage of the cognition in RBot, and RBot benefits from the presentation and graphics possibilities of 3D simulations.

Thus, our aim is to plug the RBot actor into a 3D environment and let the actor interact with the environment based on the perceived signs from that environment and other actors that are in that environment. The challenge of the project will be to see if we are able to plug our RBot actor in an already existing environment; an environment that will function as a replacement of our simple

MRS environment.

Remaining work

There will be many tasks to fulfil besides the projects. In parallel with the projects, we will create new experiments, tests and enhancements for our RBot actor and MRS environment.

Another aspect is that we didn't pay enough attention to the data presentation and the graphical user interface of RBot and MRS. At this moment, the number of users of RBot consists only of four users. However, when the application needs to be deployed to a larger community, then the user interface requires a lot of work for making RBot accessible and user-friendly.

From an organisational point of view, we are interested in creating simulation experiments that concentrate on coordination of tasks. The experiments fall in line with Computational & Mathematical Organization Theory, i.e. we want to test cooperation and conflicts in the distribution of tasks/goals. Although such experiments will be theoretically, they can contribute to a better understanding of an effective organisation of distribution of tasks, i.e. they allow us to create formal tests about organisation theories.

Besides some new theoretical experimentation and design improvements of RBot, probably the most important tests to conduct in case of RBot is a further external validation of RBot with the help of empirical testing and evidence, especially where innovations with respect to the already tested ACT-R architecture are concerned.

Because we agree that such testing is important, we devote our last remarks of this dissertation to the issue of empirical testing. The dissertation that is in hands of the reader is an instrument that needs to be validated with help of empirical experiments. Although we are aware that there is a lack of empirical evidence that enables the reader to test its validity, we state that digging for the right answers first requires the right spade and such a spade only comes with experience.