Summary

A Compositional Semantic Structure for Multi-Agent Systems Dynamics

Since a number of years, *multi-agent systems* have attracted considerable attention in Computer Science and Artificial Intelligence. A multi-agent system is a software (or hardware) system that consists of a set of co-operating, autonomous parts, called agents. For analysis and design, specification formalisms are needed that are especially suitable for such systems. To enable automated support for the analysis and design process, the semantics of such formalisms has to be described precisely.

The semantics of a specification formalism consists of a mapping of expressions of the formalism onto a set of concepts and relations between these concepts that is sufficiently rich to express the intended semantics. In this thesis, such a set is called a *semantic structure*. To enable the precision mentioned above, the semantic structure itself is described with the help of formal, mathematical notions.

The goal of the research described in this thesis is the development of a semantic structure for the description of the dynamics of multi-agent systems. Due to the specific characteristics of multi-agent systems, four requirements are stated with which the semantic structure should comply: (i) the semantic structure should support the description of both the internal dynamics of an agent and of the interaction between agents, (ii) the description of dynamics should be compositional (i.e., the behaviour of a system is described in terms that refer to the behaviour of the parts that make up the system), (iii) dynamics should be described in terms of states and state transitions of the agents, and (iv) the dynamics of a specific part of a system should be described in terms that only refer to this part (and possibly to its constituents). In other words, it is not possible to take a notion of state at a global or systems level as the basis for the semantic structure. These requirements are further described in Chapter 1.

The starting point for the development of the semantic structure is the assumption that a multi-agent system can be modelled as a *compositional system*. A compositional system is understood to be a system that consists of *components* and connections between these components: *information links*. A component is a locus of

information and computation that processes this information. A component offers services to other components, and is able to use services offered by other components. Information exchange necessary for the use of services takes place via the information links between components. A component may be composed of other components, which gives rise to a recursive system structure.

The starting point for the development of the semantic structure is further elaborated in Chapter 2 and Chapter 3. In Chapter 2, the notion of a component is described in more detail, and a number of choices with respect to the mechanism of information exchange between components are discussed. The development of the semantic structure requires that commitments are made to a number of these choices. Chapter 3 discusses how a multi-agent system can be modelled as a compositional system, again including a number of choices that have to be made. However, for the further development of the semantic structure, commitments to specific choices presented in Chapter 3 are not required.

Chapters 4 to 7 contain the formal description of the semantic structure. Chapter 4 describes, in an informal way, the central construct in the semantic structure, which is formally elaborated in Chapter 5. In addition, an example is introduced that is used in the next chapters to illustrate the semantic structure. A description of the dynamics of a compositional system in terms of the semantic structure consists of *traces*, one for each component. A trace is a sequence of *local states* of the component. A local state of a component only includes (descriptions of) the state of that component, and not of any other component. Only local traces that are *compatible* may occur together in the set of traces that describes the behaviour of a compositional system. Local traces of two components that are connected by an information link are compatible if the traces respect information exchange as described for this link: in essence, information that is sent in one trace should be received in the other. (Local traces of two components that are not connected by an information link are compatible by definition.)

Chapter 5 first presents formal definitions for the notions introduced in Chapter 2 and Chapter 3. These notions determine the non-dynamic structure of compositional systems. Three views on the behaviour of a compositional system are formally defined. These three views differ in the extent to which the behaviour of subcomponents is visible: not at all, only for one level, or fully. Chapter 6 elaborates upon the notion of compatibility. The choices described in Chapter 2 with respect to the mechanism of information exchange are presented in this chapter as properties of compatibility relations between sets of local traces. Chapter 7 shows that, starting from the concepts presented in Chapter 5 and Chapter 6 (that do not rely on a notion of global state), it is possible to define a notion of global state, without referring to a notion of global (synchronised) time. The notion of global state is compared to similar notions that can be found in the literature.

Chapter 8 is devoted to modelling control within the semantic structure and within multi-agent systems. Due to the supposed autonomy of agents, modelling control is subject to constraints. Control is understood to be information transmission from one component, to a component that is to be controlled, with the intention of influencing the behaviour of the component that is to be controlled. In this way, it is possible to describe control in terms of the semantic structure without the need to extend the semantic structure, and without compromising the autonomy of controlled components.

Chapters 9 to 11 present applications of the semantic structure. In these chapters, the DESIRE modelling framework plays a central role. The DESIRE modelling framework provides a partially graphical and partially textual language for the specification of multi-agent systems. The language is sufficiently rich to enable automatic generation of prototypes of the systems that are specified. Chapter 9 presents a detailed description of the semantics of DESIRE specifications in terms of the semantic structure, with emphasis on the dynamics of multi-agent systems specified using DESIRE. In Chapter 10, a model for co-operation to establish mutually exclusive access to a resource is specified using DESIRE. In this model, a small number of agents with a complex structure co-operate. In contrast, in Chapter 11, a DESIRE-specification of altruistic behaviour between a relatively large number of simple agents is presented. A way to analyse both specifications is sketched, based on the semantics in terms of the semantic structure.

The final chapter of this thesis, Chapter 12, contains an evaluation of the semantic structure with respect to the requirements put forward in Chapter 1. Moreover, the approach presented in this thesis is compared to a number of other approaches that can be found in the literature.