Chapter 3

Multi-Agent Systems as Compositional Systems

The previous chapter presented a number of commitments with respect to the constructs and relations that together constitute the semantic structure for compositional systems developed in this thesis. The commitments, which are not specific to multi-agent systems, are fixed for the semantic structure, and consequently, all applications of the semantic structure necessarily use the constructs committed to in the previous chapter.

As stated in Chapter 1, the aim of this thesis is to develop a compositional, formal semantic structure that can be used for multi-agent systems dynamics. Thus, the semantic structure is intended to be applied in the domain of *multi-agent systems*. More specifically, the intended use of the semantics structure is to provide semantics for models of multi-agent systems, (in particular their dynamics), or for specification languages. As the basic assumption, stated in Chapter 1, is that multi-agent systems are modelled as *compositional systems*, the semantic structure presented in the previous chapter provides constructs for building compositional systems. The most important issue for applications of the semantic structure is thus: *how can multi-agent systems be modelled as compositional systems*. This is the topic of this chapter.

The previous chapter discussed different possibilities for commitments to specific constructs and relations between constructs, and explicitly fixed a set of commitments. As the commitments discussed in the previous chapter determine the contents of the semantic structure, it was necessary to commit to a specific set of constructs. However, in this chapter, different possibilities for modelling multi-agent systems are discussed, without committing to specific choices. There is no need to commit to a specific way of modelling multi-agent systems, because for each application, different choices can be made.

The discussion of modelling multi-agent systems is organised as follows. First, the basic principle of modelling multi-agent systems as compositional systems is explained in Section 3.1. Section 3.2 provides further guidelines for modelling multi-agent systems as compositional systems by presenting a generic compositional agent model. Section 3.3 discusses possible ways to model various phenomena of multi-agent systems, which should be regarded an illustration of the application of compositionality in the area of multi-agent systems. Moreover, some issues that are treated in more detail in later chapters, are also raised in this section.

3.1 Multi-Agent Systems as Compositional Systems

In Chapter 1, a multi-agent system is defined as a group of agents together with their common, shared environment. The basic assumption adopted in this thesis is that multi-agent systems are modelled as compositional systems. Thus, an application of the semantic structure has to identify entities within a multi-agent system that are represented by components in the application of the semantic structure. This section discusses a guideline that can be followed in constructing a model of a multi-agent system as a compositional system.

The starting point is to focus on a multi-agent system as a *system*. A system is often defined as a connected collection of parts (see e.g., Oxford Concise Dictionary, and Wieringa, 1995). As the semantic structure focuses on multi-agent systems *dynamics*, in this thesis, a system is seen as a coherent collection of *processes and entities that execute processes (agents and the environment)*. (This perspective, which includes explicit focus on processes, may be considered to be a dynamic variation of the definition cited above.) It is understood that any pattern of change within a system constitutes a process. In addition, the interpretation of *coherence* is deliberately left vague: it merely indicates that some relationship between the processes in a system must exist. The guideline consists of the following four steps:

- First, in a multi-agent system that has to be modelled, processes are identified. Moreover, these processes can either be classified as deliberation processes or environmental processes (Section 3.1.1);
- Then, (active) entities are identified (the agents and the environment) that execute the processes. An agent or the environment can execute more than one process simultaneously (Section 3.1.2);
- After that, a multi-agent system is modelled as a compositional system (see Chapter 1), which is achieved by representing each process as a component. This component encapsulates both the information used by the process and the process (computation) itself (Section 3.1.3);
- Finally, relations between processes and between processes and the agents or the environment have been identified (Section 3.1.4).

3.1.1 Deliberation Processes and Environmental Processes

It is assumed that processes can be classified as either deliberation processes or environmental processes. Deliberation processes, which are always internal to an agent, comprise the main activity of an agent. Deliberation is needed (1) to acquire information by communication with other agents or by observing the environment, (2) to process information, and (3) to initiate actions or transmit information to other agents. Deliberation processes identified in the multi-agent system are represented by components in a compositional system that models the multi-agent system. As stated in Chapter 2, a component is a locus of information and computation. Deliberation processes are thus modelled as computational processes.

Environmental processes are processes that are executed by the environment. In other words, environmental processes are the processes identified in a multi-agent system that are not internal to an agent. Similar to deliberation processes, environmental processes are represented by computations in a compositional system that models a multi-agent system.

It is assumed that interaction is *not* identified as separate processes, but as "mutual or reciprocal action or influence[5]", thus as a relation between processes (relations between processes are discussed in Section 3.1.4). Moreover, interaction is not a basic concept. Three forms of interaction are distinguished: communication, action execution and observation. (Which instances of interaction are viewed as communication, action execution or observation differs from application to application and is discussed as a modelling choice in Section 3.3.3.) In addition, interaction is viewed as consisting of two (or more) instances of *unilateral* influence from which "mutual or reciprocal influence" emerges. Thus, like information exchange (see beginning of Section 2.2), interaction is viewed as inherently composed.

Exactly which processes are distinguished as deliberation processes and which as environmental processes is subject to modelling choices discussed in Section 3.3 below.

3.1.2 Agents and the Environment

It is assumed that specific entities in a multi-agent system can be identified as agents and others as the environment. How this identification is to be performed is viewed as a process akin to traditional knowledge acquisition or requirements engineering and is outside the scope of this thesis. (Compared to traditional knowledge acquisition or requirements engineering, there is much more emphasis on acquiring knowledge that supports the autonomy and social ability of an agent compared to knowledge of the agents' specific tasks. An approach to agent-based knowledge acquisition is presented in (Iglesias, Garijo, González & Velasco, 1998). See (Iglesias, Garijo & González, 1999) for a survey of such approaches.) However, it is assumed that entities identified as agents in the multi-agent system exhibit the agent characteristics presented in Chapter 1: autonomy, reactivity, pro-activeness and social ability (Wooldridge & Jennings, 1995b).

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[5] Merriam-Webster WWWebster Dictionary (http://www.m-w.com/).

It is also possible that specific entities in a multi-agent system are identified as subagents of another agent. In this case, it is assumed that subagents are themselves agents: a subagent must also be autonomous, reactive, pro-active and socially able. Only subprocesses of an agent for which these properties are important should be distinguished as subagents. On the one hand, subprocesses for which these properties are not important should not be considered agents. As stated above, a subagent is assumed to be an agent itself, and therefore, such subprocesses should not be distinguished as subagents. On the other hand, processes for which the properties mentioned above are important, are assumed to be to be distinguished as agents. As these processes are subprocesses of another agent, they should be distinguished as subagents to explicitly represent the hierarchical relation between agents in the multi-agent system. Often, processes can be distinguished that co-ordinate the activities of the (autonomous) subagents. These processes themselves may be associated with some of the subagents, as is indicated by the following example. Consider a team of agents. At a specific level of analysis, the team members are abstracted from and the team itself can be viewed as an agent: it is autonomous, reactive, pro-active, socially able and can be ascribed a mental state. (E.g., one can identify the intention of the team.) At another level of abstraction, the individual team members are identified and viewed as (autonomous) agents. Team members may exercise their autonomy to leave the team or to pursue goals that are incompatible with the team's intentions. Specific team members may adopt the goal of keeping the team together and establishing the team's intention as the joint intention of each member. A more detailed investigation of the relationship between mental attitudes of a team and of its members can be found in (Singh, 1998).

3.1.3 Processes and Components

Each process distinguished in a multi-agent system is represented by a component in the compositional system that models the multi-agent system. Processes identified in the multi-agent system are classified as either deliberation processes or environmental processes. A component that collates all deliberation processes of a specific agent in fact *represents* this agent in the compositional system. However, the guideline presented in this chapter does not *define* which components are agents and which are not. Instead, the guideline assumes that, as a starting point, an analysis of the multi-agent system has already identified which entities in the system are agents, and, as explained in the previous section, it is assumed that these agents exhibit agent characteristics such as autonomy, reactivity, pro-activeness and social ability (Wooldridge & Jennings, 1995b; see also Chapter 1). As a consequence, not only the agents in the modelled system exhibit agent characteristics, also the components that represent the agents do. However, these characteristics are not explicitly represented characteristics of the component construct or any other construct provided by the semantic structure.

3.1.4 Relations between Processes and between Processes and Agents or the Environment

It is assumed that three different types of relations can be identified in a multi-agent system, each of which is represented in a different way:

- There is a hierarchical relation between processes: a process may consist of other processes (the subprocesses of the process), which themselves may consist of other processes, and so on. The level of (process) abstraction determines which processes are considered to be primitive (no subprocesses are distinguished). Process composition is studied extensively in the area of Process Algebras (Bergstra & Klop, 1985; Milner, 1980; Hoare, 1978). Many languages for the specification of dynamics distinguish composition operators taken from the area of Process Algebra (Eck, Engelfriet, Fensel, Harmelen, Venema & Willems, in press). The hierarchical subprocess relation is identified with the subcomponent relation in the compositional system that models a specific multi-agent system.
- As stated before, a multi-agent system consists of a group of agents together with their common, shared environment. Processes in a multi-agent system either take place in the environment, or in one of the agents. The second relationship associates processes with the agent or the environment in which they take place. This relation is represented in a compositional system that models a multi-agent system as follows. At the highest level of abstraction, a compositional system that models a multi-agent system consists (solely) of one component for each agent and one component for the environment. At lower levels of abstraction, all subprocesses distinguished in the multi-agent system are represented as subcomponents of either one of the agent's components or of the environment component, according to whether they are associated with that agent or with the environment in the multi-agent system. As a consequence, the structure of a multi-agent system (different agents and the environment) is thus also represented in the compositional system.
- A process consumes information provided and produces new information, which can, in turn, be consumed by other processes. By providing information to another process, a process can influence the other process. This influence establishes the third relation between processes. In a compositional model of a multi-agent system, this relation is represented by information links between components. Interaction, which is characterised as mutual influence, is an important example of this relation.

As stated in Section 3.1.1, interaction is viewed as a relation between processes. With respect to interaction, two different aspects are distinguished. First, an agent performs deliberation processes that determine when and how to communicate, initiate actions or perform observations. These deliberation processes are modelled as discussed above. The second aspect is the interaction proper, which is modelled by information exchange between components in the compositional system that models a multi-agent system.

Three forms of interaction can be distinguished: communication (information transmission from one agent to another), action execution, and observation. Information transmission from one agent to another resembles the information transmission construct presented in Section 2.2. Consequently, information transmission from one agent to another (communication) is represented by information transmission from one component to another in a straightforward manner.

In a compositional system model of a multi-agent system, action execution and observation of the environment are also represented by the information transmission construct presented in Section 2.2. This is possible because not only processes associated with agents are represented by components, but also processes associated with the environment. According to Pednault (1987), the effect of an action is “to cause the world to jump from one state to another”. Thus, actions are executed because of their effect on the state of the environment. In a compositional model of a multi-agent system, action execution is assumed to be modelled in terms of the effect on the state of the environment. Under this assumption, the information transmission construct presented in Section 2.2 is applicable, as this construct represents information transmission in terms of the effect on the states of the components involved in the transmission. In other words, action execution is viewed as a form of information transmission to a process in the environment that carries out the effects of the action in the environment. Observation is viewed as information transmission from the environment to the agents. (In some domains, also so-called active observations are distinguished. An active observation is an observation that is explicitly initiated by an agent and thus comprises information transmission from the agent to the environment as well as information transmission from the environment to the agent).

In Chapter 9, the semantic structure developed in this thesis is applied to provide a semantics for the multi-agent modelling framework DESIRE. In DESIRE, knowledge structures used in components are explicitly represented, and composition relations for knowledge structures are defined. As a result, additional relations on processes are identified, such as a relation that determines which knowledge structures are used by which components (Brazier, Jonker & Treur, 1998).

3.1.5 An Example

The guideline is illustrated in Figure 3.1. The left half of Figure 3.1 depicts two agents in their environment (the world). The agent on the left transmits information to the agent on the right by means of a telephone call. The agent on the right interacts with the world (depicted by the large arrow). The gearwheels represent processes distinguished in the multi-agent system, some of which are associated with the agents and another with the environment. In this figure, some processes associated with the agents are recognised as subprocesses (small gearwheels inside larger gearwheels). The right half of Figure 3.1 depicts a compositional model of the multi-agent system on the left. The top component represents the process associated with the environment. The two components below the top component represent the processes of both agents and contain subcomponents that represent the subprocesses depicted on the left half. Arrows to and from (the component that represents) the environment represent interaction between one agent and the environment. The arrow between the two agents (components) represents information transmission between the two agents. This figure depicts a possible way of representing agents and the environment. A discussion of different ways to represent interaction between agents and the environment is presented in Section 3.3.1.

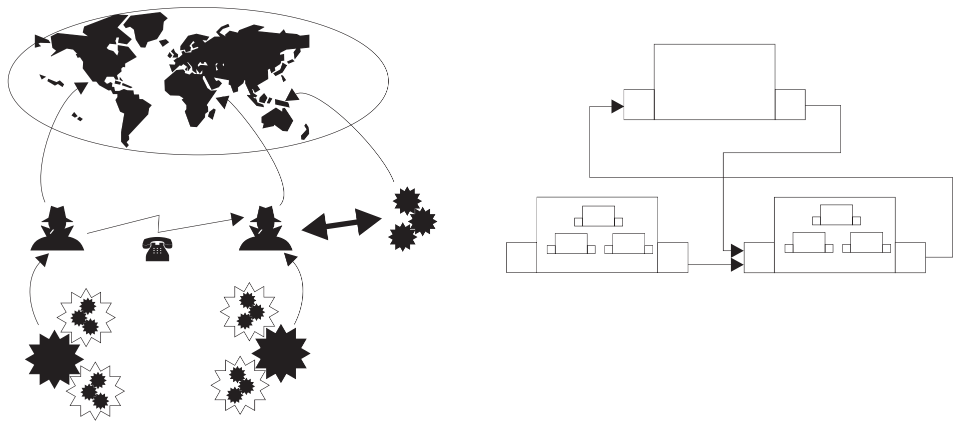

Figure 3.1: A multi-agent system modelled as a compositional system.

3.2 A Generic Compositional Agent Model

This section presents further guidelines for modelling a multi-agent system as a composition system. The guidelines are based on the concept of a generic agent model, which is introduced in Section 3.2.1. In Section 3.2.2, a specific generic agent model is described.

3.2.1 The Concept of a Generic Agent Model

As stated in the previous section, the main activity of an agent is deliberation, which is needed to acquire information by communication with other agents or by observation of the environment, to process information, and to perform actions or transmit the results to other agents. An agent’s deliberation determine its autonomy, reactive and pro-active behaviour and its social abilities, the characteristics that define an agent according to the weak notion of agents originally proposed by Wooldridge and Jennings (1995b) and discussed in Chapter 1.

This general characterisation may serve as a guideline for the identification of processes in a multi-agent system. For each agent in a multi-agent system, processes can be distinguished that perform the deliberation necessary for interaction with the environment, communication and processing information. A number of these processes are independent of the specific characteristics of a specific agent in a multi-agent system. This enables the use of a *generic agent model* as a starting point for modelling a specific multi-agent system. A generic agent model consists of components that represents top-level, generic processes that usually can be distinguished for an agent in a multi-agent system. Modelling a specific multi-agent system consists of *refining* the generic model. Refinement of a generic model involves *specialisation* and *instantiation*. Specialisation of a generic agent model entails identification of additional subprocesses of the processes identified in the generic model. These subprocesses are represented by additional subcomponents in the generic agent model. Instantiation of the generic agent model entails determination of further, specific characteristics of the processes identified in the generic model. By instantiation and specialisation, the generic agent model is transformed into a compositional model of an agent that can be used in a model of the complete multi-agent system. Results of these efforts, i.e. specific models, differ in the refinement and relative importance of the subcomponents.

3.2.2 Description of a Generic Agent Model

The current section presents a generic agent model called GAM. The generic agent model consists of processes that are not specific to an individual agent in a multi-agent system, but are, in principle, performed by each agent to manage communication, action execution and observation. In the current section, these generic agent processes are distinguished and described in more detail, leading to a compositional model of an individual agent.

The generic agent processes are related to the four characteristics required for the weak notion of agency described by Wooldridge and Jennings (1995b) and introduced in Chapter 1. In accordance with this notion, agents must (1) maintain interaction with their environment like observing and performing actions in the world: *reactivity*; (2) be able to take the initiative: *pro-activeness*; (3) be able to perform social actions like communication and co-operation: *social ability*; and (4) operate without the direct intervention of other (possibly human) agents: *autonomy*. In the generic agent model GAM depicted in Figure 3.2, these processes are each represented by a different component. Eight subcomponents are distinguished: Own Process Control (OPC), Maintenance of History (MH), Agent Specific Processes (ASP), Co-operation Management (CM), Agent Interaction Management (AIM), Maintenance of Agent Information (MAI), World Interaction

Management (WIM) and Maintain World Information (MWI). The names of the components are the same as in e.g. (Brazier, Jonker & Treur, 2000), with one exception: the component Agent Specific Processes was formerly known as Agent Specific Tasks. The term 'world' in the component names is synonymous with 'environment'. The term 'interaction' is qualified with either 'agent' or 'world' to indicate communication or action execution / observation, respectively.

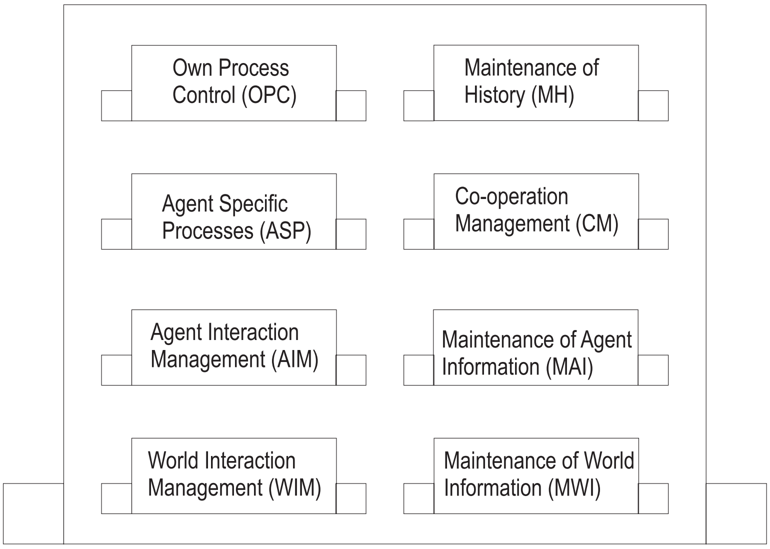

Figure 3.2: Top-level composition of the generic agent model GAM, from (Brazier, Jonker & Treur, 2000).

The following three points provide some background on the generic agent model:

- The correspondence with the four characteristics described above is as follows. Action execution and observation are performed by World Interaction Management, also using Maintain World Information. Social actions are managed by the processes Agent Interaction Management, Maintenance of Agent Information and Co-operation Management. Performing the agent's processes is co-ordinated by the component Own Process Control. This enables the agent to act autonomously and take the initiative if required. Most often, the eight subcomponents are further refined. This is illustrated in e.g. Chapter 10 and Chapter 11, in (Brazier, Dunin-Keplicz, Treur & Verbrugge, 1999), which presents a model of BDI agents designed as a refinement of GAM, and in (Brazier, Jonker & Treur, 1997), which presents a model for co-operation based on GAM. However, it is also possible that in specific agents, one or more of the generic components are not used.

- As stated in Section 3.1.2, knowledge acquisition is required to identify deliberation processes and environmental processes in a multi-agent system. The subprocesses distinguished guide agent-based knowledge acquisition, as the processes determine the various types of agent-specific knowledge required in addition to knowledge of the specific tasks an agent has been delegated. This includes (1) knowledge of an agent's priorities with respect to controlling its processes, (2) knowledge of which and how information is exchanged with other agents and the environment, (3) knowledge of how information received from the environment and other agents is to be analysed and (4) knowledge of how co-operative an agent is in given situations in relation to other agents.
- The compositional model depicted in Figure 3.2 is based on analysis (e.g., in the ARCHON project, see (Cockburn & Jennings, 1996; Brazier, Dunin-Keplicz, Jennings & Treur, 1997)) and considerations regarding the properties an agent should have as described above. This compositional model is the starting point for the models presented in Chapter 10 and Chapter 11. Moreover, for instance in (Brazier, Dunin-Keplicz, Jennings & Treur, 1997), the same model is applied to agents performing a process diagnosis and control task, with a minor shift in relative importance of the subprocesses.

3.3 Modelling Choices

As stated in the introduction of this chapter, the guideline for modelling a multi-agent system provides a considerable degree of freedom with respect to exactly how a multi-agent system is modelled. This section presents a number of issues deliberately left open by the guidelines presented in Section 3.1 and Section 3.2 and discusses various alternative ways of resolving these issues. As stated in the introduction, no commitment to specific alternatives is made. Such commitments are neither necessary for the further development of the semantic structure nor desirable, as the best alternative likely depends on the requirements imposed by a specific application.

3.3.1 The Environment and Interaction

As stated in Section 3.1.4, action execution and observation are represented by information transmission between a component that represents an agent and a component that represents the environment. This is possible because not only processes associated with agents are represented by components, but also processes associated with the environment. Section 3.1 assumes that processes identified in a multi-agent system can be classified as deliberation processes (which are internal to agents) and environmental processes. This classification is expected to be straightforward for most processes. However, depending on properties of a specific multi-agent system and on the goal of the modelling effort, for some processes the classification may be more difficult. This holds in particular for processes that execute actions that affect other agents.

From the perspective of an agent, all other agents appear as entities in the environment it shares with the other agents. Consequently, it is, in principle, possible to observe other agents and to initiate actions that (directly) affect other agents. (E.g., hitting other agents.) In many multi-agent systems, however, this aspect of other agents can be abstracted from, because in such a multi-agent system, agents only communicate with each other and are not interested in executing actions upon one another or observing each other. In this case, agents are not represented in the environment. Instead, only non-agent entities are represented in the environment.

From the perspective of a single agent, also specific aspects of the agent itself are present in the environment, as an agent is not only a collection of mental deliberation processes (the mind), but also matter that constitutes the location of the mind. In many multi-agent systems, it is also possible to abstract from these material aspects. However, in some cases it is necessary to represent actions executed upon the agent, such as e.g. being hit by another agent (or the agent itself). In these cases, the material aspects of an agent and its mind may influence each other (e.g., brain damage and psychosomatic diseases).

Whether material aspects of agents are modelled depends on properties of a specific multi-agent system, together with the goal of the modelling effort. In this section, architectures for two alternatives are sketched. The most complex alternative presented covers mutual influence of an agent's mind and matter. This alternative is taken from (Jonker & Treur, 1997), which studies the interaction between an agent's mind and matter in great detail.

The first alternative, depicted in Figure 3.3, is adopted from Figure 10 in (Jonker & Treur, 1997). The left half of Figure 3.3 depicts an environment with one agent (Agent A) and one non-agent object (a car). Processes relating to material aspects of Agent A as well as its mental processes are distinguished. The processes relating to material aspects of Agent A are considered to be subprocesses of a process that collates all processes associated with the environment. Other subprocesses of this process are e.g. the processes executed by the car. The multi-agent system is represented by the compositional system depicted on the right half. The component labelled Agent A represents the mental processes of Agent A. The component labelled Environment represents the process that collates all processes associated with the environment. Two subcomponents are distinguished in the environment. The component labelled C represents the processes relating to the car. The component labelled A represents the processes relating to the material aspects of Agent A. The link labelled 1 is used to represent the influence of the material processes of A on its mind. The link labelled 2 transmits observation results from the environment to Agent A. The mediating link connected to this link and starting at component C can be used for observations of the car. (E.g., information on the speed of the car can be transmitted via this mediating link and link 2 to Agent A.) Link 3 is used by Agent A to initiate actions in the environment. The link is connected by a mediating link to component C. This mediating link can be used to execute actions upon the car (e.g., starting it). The link labelled 4 represents the influence of Agent A's mental processes on its material aspects.

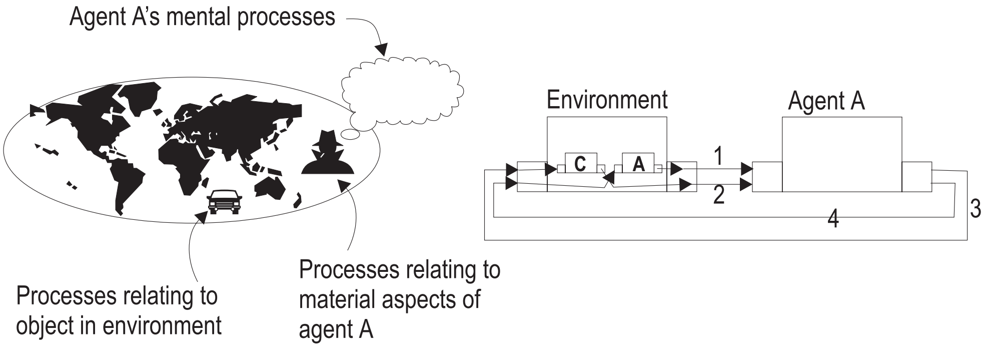

Figure 3.3: Modelling mind and matter.

The second alternative, which is more common, is a less detailed version of the model depicted in Figure 3.3. If the properties of the multi-agent system nor the goals of the modelling effort require explicit modelling of Agent A's material processes, the component labelled A as well as the links labelled 1 and 4 can be omitted from the model.

3.3.2 Observability of Actions and Processes

A common connotation of environmental processes is that these processes are, in principle, observable (and deliberation processes are not). This does not imply, however, that all processes in the environment are unconditionally observable for all agents in a multi-agent system. (As an example of a multi-agent system in observability of processes in the environment, consider the multi-agent system modelled in Chapter 11. This system consists of a society of 30 relatively simple agents that wander about in search of food, and, depending on their character, may choose to help other agents in finding food. Each agent has a limited range of vision. Processes that take place in a part of the environment too far away cannot be observed.) Whether all processes are observable for all agents in the environment is a property of a specific multi-agent system and thus varies between models.

As explained in Section 3.1.4, action execution and observation are represented in a compositional model by the construct for information transmission provided by the semantic structure. This construct only supports point-to-point information transmission (the commitment presented in Section 2.2.2). Therefore, action execution and processes are only observable for components for which there is an information link that connects them to these processes. Thus, by carefully choosing which components in the environment to connect to which agent components, it is possible to model e.g. some processes as observable to specific agents and other components as observable to other agents. (Another possibility is to connect all agent components to the environment component, using the *state* of links to *dynamically* determine which processes are observable to specific agents.) As processes in the environment are affected by action execution, the same flexibility can be applied to choose which action executions are observable and which are not.

As a result of the flexibility with respect to whether processes are observable, there is an abundance of modelling choices. The following two alternatives might serve as general principles for the observability of action execution. The first alternative is to assume that an action always results in an observable change of the world state. This assumption is controversial. Consider for instance the situation in which two agents, A and B, both need to acquire exclusive access to a certain resource. First, A and B simultaneously observe the environment and find that the resource is still free. Then both try to take the resource. Assume that A is faster and thus acquires the resource, while B does not. However, both may observe that the resource is no longer free, so both infer that the action has been successfully performed. B's action only appeared to have resulted in an observable change of the world state, because in a sense B observed the situation before A acquired the resource and missed the fact that this has happened.

As an aside, a decentral model for mutually exclusive access to a shared resource is presented in Chapter 10.

The second alternative is to assume that an action is considered to have been successfully performed even if the world state has not changed. When the second option is used, it is not possible to determine whether the execution of an action is completed by observing the state of the world. In this case, it should be possible to observe the execution of an action itself.

3.3.3 Communication as Action Execution

As stated in Section 3.1.4, information exchange between agents (communication, one of the basic activities of an agent) is represented by information links between components that represent agents. A basic connotation of information transmission is that both the transmission and the information transmitted are, in principle, only observable by the agents involved in the transmission. The information transmission construct provided by the semantic structure guarantees that this is the case. (The commitment to point-to-point transmission presented in Section 2.2.2). However, there is an alternative way to represent communication. This alternative treats communication as an action in the environment and thus emphasises material aspects of communication. In the following circumstances, this alternative seems most suitable. First, in some multi-agent systems, there are forms of communication for which it is important to explicitly represent the way in which the communication takes place. Consider, for example, the multi-agent system presented by Jonker, Treur and Wijngaards (2000), who study multi-modal (verbal and non-verbal) communication. In this system, all communication is modelled as action execution (by one agent), followed by observation (by the other agent). This enables representation of disturbances by environmental influence and of non-verbal communication by manipulating objects in the environment. Second, in some circumstances, the multi-agent system modelled requires that agents not involved in the communication are able to observe the communication. An example could be a model in which fraudulent agents are modelled that eavesdrop on communication. In addition, broadcast communication can be modelled as an action in the environment. As is explained in Section 2.2.2, the semantic structure does not provide constructs for broadcast communication. However, broadcast communication can be represented as an action in the environment observable for all agents.