

Chapter 5

Empirical Modelling for collaborative modelling

In the last chapter, I have discussed the philosophical foundation of Empirical Modelling (EM) and differences to other approaches to software systems development. So far, there has been little discussion on what kind of collaborative context may be benefited by adopting an EM approach and how EM principles such as the ODA framework can be exploited in collaborative work such as groupware development. Therefore, this chapter aims to explore the potential benefits that EM may offer to collaborative model construction⁷⁷ in general and the ideal level of tool support that is essential to unlock the potential benefit that EM may offer to collaborative modelling. The idea of applying EM principles to collaborative modelling as a framework for groupware development will not be discussed in this chapter, but in chapter 7 of this thesis.

In a broad sense, collaborative modelling refers to the process of model construction among two or more individuals with a common interest, whether or not computers are used. In a narrower sense, collaborative modelling may only refer to synchronized model construction among a group of individuals. It is hard to give a strict definition of collaborative modelling due to the very diverse ways in which the modellers can interact within the collaborative modelling process. This chapter begins with a discussion of three important aspects of collaborative modelling (cf. §5.1), namely, the degree of engagement, the relationship between the modellers and the agents in the model, and the modes of interaction. On the one hand, the idea of degree of engagement here is influenced by two models of

⁷⁷ i.e. the construction of an Interactive Situation Model (ISM) collaboratively.

collaboration in the literature, namely, (Borghoff and Schlichter, 2000) and (Kaptelinin and Nardi, 2006). On the other hand, the modes of interaction are inspired by the four paradigms for Distributed Empirical Modelling (DEM) (Sun, 1999). Though these aspects do not *define* collaborative modelling, it helps us to understand the types of interaction that may be involved in constructing a model collectively.

In section 5.2, the focus moves to the historical development in EM conceptual frameworks and tool support for collaboration. Previous research into EM has shown its potential in collaborative contexts such as concurrent engineering (Adzhiev et al., 1994a) and distributed work within organizations (Sun, 1999). Tools such as the ADM, LSD and dtkeden were developed for these contexts. However, these conceptual frameworks were based on theories for well-defined organization. They paid little attention to the diversified interaction and seamless moving between different modes of interaction and activity in collaborative contexts such as groupware development. In section 5.2, I also discuss why the existing conceptual frameworks and tool support are not good enough for collaborative modelling. In section 5.3, the focus is moved to the criteria for practising EM in the different types of collaborative activities that are mentioned in section 5.1, and collaborative modelling as a whole. Section 5.3 also argues that we should provide an integrated environment instead of isolated tool support for different aspects of collaborative modelling.

5.1 Defining collaborative modelling

The term “collaborative modelling” generally refers to a model construction process that requires a collaborative effort. Depending on what model is being constructed and in which context, collaborative modelling can be “carried out” in a wide range of domains from computer-based software design modelling (e.g. with UML), modelling of an eco-system (e.g. Salles and Bredeweg, 2003), to making conceptual models with pencil and paper. There are many ways in which different scenarios for collaborative modelling can be distinguished. On the one hand, the collaboration process can be carried out with or without computers. On the other hand, modellers in the collaborative process can interact diversely, e.g. asynchronously, semi-synchronously, or synchronously. It is hard to give a strict definition of collaborative modelling due to the general use of the term “modelling” and the

diverse forms of “collaboration” that can appear in the collaborative modelling process.

Despite the ambiguity of the term, *collaborative modelling*, in this thesis, is used to refer to *the collaborative process for constructing an interactive computer-based model of a software system*. For this reason, collaborative modelling, in this thesis, should not be thought as a type of interaction or situation that may only take place in a particular configuration. It should be thought of as a process for which the aim is not an end product but a continual re-configuration of human practice. Therefore, the evolving and situated nature should be taken into account in this interpretation of collaborative modelling.

In this section, I describe three important aspects of collaborative modelling. My intention is to provide the reader with some handle on the kind of collaborative modelling that this thesis is concerned with and that will be used as the foundation for groupware development in chapter 7. These aspects play a crucial role in shaping the collaboration from time to time during the collaborative modelling process. Although they resemble a taxonomy of collaboration, they should not be viewed as one, as human collaboration cannot be “framed” by any means due to its dynamic characteristic.

As mentioned previously, the purpose of this chapter is to expose the potential of an EM approach to collaborative modelling. For this reason, the following discussion is oriented towards an EM perspective.

5.1.1 Five degrees of engagement in collaborative modelling

The idea of the degrees of engagement as discussed in this section is influenced by two models of collaboration in literature (Bair, 1989; Kaptelinin and Nardi, 2006).

Two models of collaboration

Borghoff and Schlichter (2000) describe four-level hierarchy of collaboration: inform, coordinate, collaborate, and cooperate. Their model is based on the earlier work of Bair (1989). Although the boundaries between one degree of engagement and another are not sharply defined, Bair’s (1989) research suggests that collaborations at different levels have different needs and require different communication media. Kaptelinin and Nardi (2006) describe another model of collaboration which draws on Raeithel’s (1996) three-part

scheme. Raeithel's hierarchy, in turn, is based on earlier work by Fichtner (1984). Unlike Borghoff and Schlichter, Kaptelinin and Nardi focus on the “creativity fissures” in collaboration.

Although these models of collaborative work seem compatible with each other, careful examination reveals that there are subtle differences. For instance, Borghoff and Schlichter (2000) focus on more low-level collaboration by including *informing*, which may not be considered as a form of collaboration in a strict sense. Borghoff and Schlichter (2000) suggest that people can coordinate without having a common goal (also cf. Bair, 1989), but that a common goal seems crucial to bind people together in Kaptelinin and Nardi's model of collaboration. Similarly, Borghoff and Schlichter (2000) emphasize the demand for face-to-face meeting in co-operation, such synchronized interaction is not necessary, though it is favoured, in Kaptelinin and Nardi's model of collaboration.

A unifying structure

Drawing on the above mentioned models of collaboration and our previous discussions on the evolutionary nature of group work (cf. §2.4) and the co-evolutionary phenomena in systems development (cf. §3.1), the degree of engagement in collaborative modelling can be classified into five levels: coordination, collaboration, cooperation, co-construction, co-evolution.

Coordination – Apart from *informing* as described in Borghoff and Schlichter's (2000) model of collaboration, coordination has the lowest degree of interaction and coherence in collaborative work. In this case, individuals within the group are working alone but linked together through shared resources. For activity theorists, the coordination for the collective activity takes place outside the context of individual activities (Kaptelinin and Nardi, 2006). For instance, a group of salesmen may coordinate their use of, e.g. meeting room, on a shared schedule, and that is not included in the salesmen's individual calendar.

Collaboration – In collaboration, individuals may work together in shared activity and with shared resources. However, the team may not have an explicit common goal. In this case, diverse perspectives are encouraged and some exploratory work may be required in order to shape a common goal for the collaborative work. For example, a preliminary

brainstorming meeting for design ideas in a creative artifact development is a form of collaboration without an explicit concern for how the artifact would e.g. look and feel. It is worth stressing the importance of the unifying of diverse perspectives instead of imposing a perspective at some point from an individual either external to the group or a member of the group. While the former is the source of creativity in collaborative work, the latter could suppress creativity.

Cooperation – In cooperation, individuals need to be aware of other people's work in the team, and individual adjustments might be needed in order to work towards the overall shared objective of a more complex activity than in coordination. For instance, the early stages of the transformation process of qualitative data of traffic accidents into quantitative data as reported in Spinuzzi (2003) is a highly sophisticated cooperative work that cannot be done merely by coordinating the workers. In cooperation, individual goals may have to be sacrificed for the collective goal. Moreover, due to the potential conflicts, diverse perspectives are often not possible and may not be encouraged.

Co-construction – In co-construction, individuals do not just cooperate, but are also able to evolve and refine the objective of the activity during the collaboration (Kaptelinin and Nardi, 2006). This implies that individuals may have to develop shared understandings of the collective activity and of the artifacts under co-construction. For instance, groupware development is a form of co-construction among all stakeholders, developers, and future users. Effective groupware development involves not only cooperation, but will also develop a shared understanding throughout the collaboration process, and that shared understanding, in turn, will be used in the continuous refinement of the objectives for the groupware in order to cope with the changing work practices surrounding the use of the groupware.

Co-evolution – Co-evolution has the highest degree of engagement in the collaborative work, in which the individual understandings of all objects in the collaboration process (e.g. the objective, the artifacts under co-construction, etc.) and the artifacts themselves are all co-evolving throughout the collaboration process. The boundary between co-evolution and co-construction is blurred. The only difference between them lies in the individual and the

collective understandings of all objects in the collaboration process: these understandings evolve to a greater degree in the case of co-evolution. In the context of computer-based systems development, however, co-evolution may only take place when the development team practises an evolutionary development approach in the co-construction process. In other words, co-evolution occurs through co-construction, not vice versa.

5.1.2 The relationship between modellers and agents in collaborative modelling

Artifacts play an essential role in facilitating collaboration between participants of the collaborative modelling process. Throughout the collaboration process, there is a close relationship between the kinds of interaction of the participants and the conceptual constructs in the artifact. When adopting an object-oriented approach to collaborative modelling, modellers engage and interact through sharing and co-constructing conceptual constructs (i.e. classes, objects, packages, etc). When practising an EM approach to collaborative modelling, modellers engage and interact through elaborating and negotiating observables, dependencies, and agents.

It seems self-evident that different relationships between the modellers and the conceptual constructs yield different kind of collaboration. I argue that, in fact, the relationship between modellers and agents characterises the collaboration in the context of agent-oriented computer-based modelling, such as EM. Figure 5.1 illustrates how this relationship can be roughly classified into four modelling scenarios in a two-dimensional matrix. It is the shaded areas in figure 5.1 that are classified as collaborative modelling.

For the sake of completeness, the following discussion includes “single modeller” modelling scenarios. Although such scenarios may involve a degree of collaboration between the modellers outside the modelling scenarios (e.g. through sharing the models), and may also involve discussion between modellers (cf. Harfield, 2008), “single modeller” modelling scenarios alone are not considered as collaborative modelling in the context of this thesis.

	Single modeller	Multiple modeller
Single agent	Single modeller single agent (SMSA)	Multiple modellers single agent (MMSA)
Multiple agent	Single modeller multiple agents (SMMA)	Multiple modellers multiple agents (MMMA)

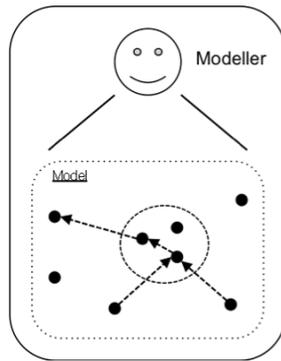
Figure 5.1 – Collaborative modelling scenarios

Single modeller single agent (SMSA)

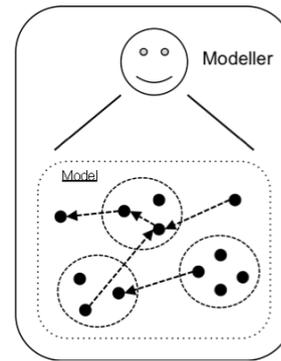
In this scenario, as shown in figure 5.2a, the modeller focuses on a particular agent. In EM, such a scenario requires the modeller to observe its referent and interact with the agent both in the role of an external observer (“externally”) and in role of the particular agent being studied (“internally”) (cf. figure 4.2). For instance, the modeller may investigate the relationship between the observables and dependencies within the agent; or the modeller may make internal observation to see how the agent interacts with other agents in the model. When such modelling is carried out as a part of a coordinated work activity, there is overlap between the observations made by different modellers and there is no real-time interaction among them. In the other words, a larger work may be divided into non-overlapping contexts in which individual modellers can carry out private modelling based on their personal observation.

Single modeller multiple agents (SMMA)

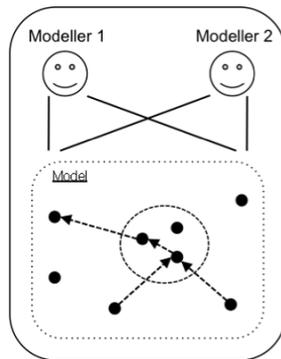
In this scenario, the modeller is managing multiple agents in the model and is mainly focusing on the interaction among the agents through external observation (cf. figure 5.2b). Such a modelling scenario is an embryonic form of the more complicated scenario – multiple modellers multiple agents – that will be described later in this section. In EM, the issue of agent identification is topical in this modelling scenario, because agency in EM is evolving in responds to the modeller’s mode of observation and state-as-experienced (cf. §4.1). For instance, after the modeller has obtained further insight in the context of observation, a single agent may be decomposed into multiple agents, an agent may disappear, or the boundaries between agents may be changed.



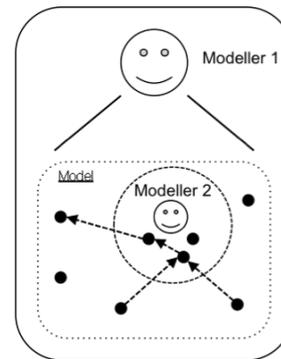
(a) Single modeller single agent



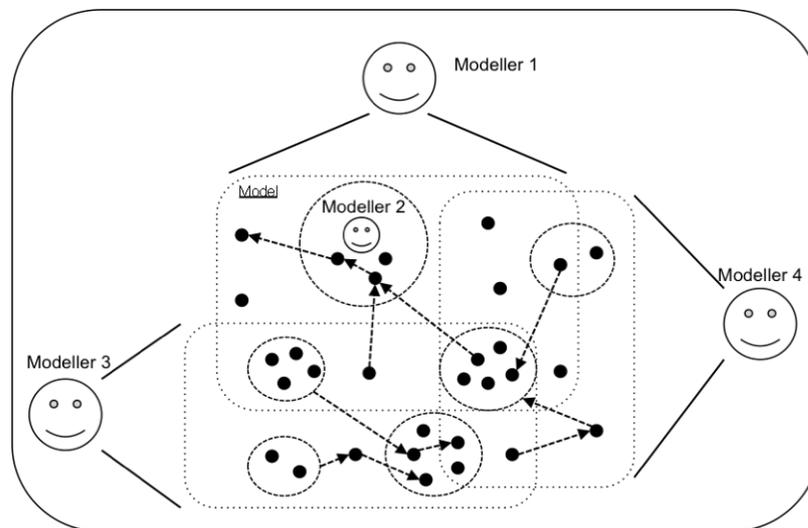
(b) Single modeller multiple agents



(c) Multiple modellers single agent (both modeller observe externally)



(d) Multiple modellers single agent (one modeller observes externally, one modeller observes internally)



(e) Multiple modellers multiple agents

Figure 5.2 – The relationships between modellers and agents in the model⁷⁸

⁷⁸ The interpretation of the above diagrams follows the convention introduced in figure 4.1 (on page 103).

Multiple modellers single agent (MMSA)

Occasionally, multiple modellers may collaborate around the same agent in the model in the collaborative modelling process. As illustrated in figure 5.2c, collaboration of this kind may occur, for instance, in the context of pair modelling⁷⁹, where a pair of modellers focus on the same agent with the aim of to co-constructing, co-examining, or negotiating the properties⁸⁰ of the agent through external observation. Similar collaborations can occur among three or more modellers.

However, the more interesting situation in the MMSA relationship arises when modellers are collaborating around the same agent with diverse perspectives. In EM, this refers to the situation where one modeller makes internal observation and plays the role of the agent while the other modellers observe externally. Figure 5.2d, for simplicity, depicts this situation with two modellers – while modeller 1 is acting as an external observer, modeller 2 is exploring plausible definitions or redefinitions (cf. figure 4.4). This “diverse perspectives” MMSA, for instance, can be invoked when modeller 2 is demonstrating to modeller 1 how the agent might interact with other parts of the model (i.e. apprenticing), or when modeller 2 is performing exploratory experimentation while both modellers are making sense of the results of experimentation from different perspectives, one internally, one externally.

Multiple modellers multiple agents (MMMA)

The “multiple modellers multiple agents” scenario is the most interesting, but also the most complicated, relationship between the modellers and the agents in the model. In a simplistic view, when collaboration is ignored, the MMMA scenario can be thought as a scaffold scenario from the “single modeller” modelling scenarios – each of the modellers is in fact managing one (i.e. SMSA) or more (i.e. SMMA) agents in the model. However, the interaction between modellers through the agents in the model is not straightforward. When collaboration is taken into account, there can be many possible scenarios. For instance, as

⁷⁹ The term “pair modelling” is used by analogy with the notion of pair programming in extreme programming (Beck 1999). The term ‘modelling’ is used in place of ‘programming’ to emphasize the broader context of collaboration, in contrast to collaboration around a program in the programming context.

⁸⁰ Not to be confused with “the attributes of an object” in the sense of object-oriented modelling. *Properties* here means the characteristics, constituency, and boundary of the agent.

figure 5.2e depicts, it is possible that some modellers are observing a particular agent internally and playing its role in the model (cf. modeller 2), while others are observing or interacting with multiple agents externally (cf. modeller 1, 3, and 4). Moreover, modellers who are observing externally may focus on a different set of agents, whether many agents or a single agent, from time to time.

Although the above-mentioned scenarios are somehow similar to Sun's (1999) distributed modelling scenarios (cf. §5.2), the notion of collaborative modelling described in this thesis concerns not only playing the role of a particular agent through internal observing (I-modelling in Sun's sense), but the overall dynamic process of internal and external observation in such a MMMA situation.

5.1.3 The modes of interaction in collaborative modelling

The *modes of interaction* refer to communication or interaction patterns between modellers that relate specifically to interaction via the artifact (or model) and the computer-based tool support that is being developed throughout the collaborative process⁸¹. The concept, on the one hand, is inspired by the four communication paradigms that are closely associated with Sun's (1999) Distributed Empirical Modelling (DEM) framework. On the other hand, it is highly influenced by the possible *communication networks* in groups (Baron et al., 1992). Some of these patterns were incidentally found in a number of pilot experiments and case studies (cf. chapter 6) that are associated with the research work behind this thesis, and some were derived from the paradigms in DEM. With reference to Johansen's (1988) spatial-temporal classification, the modes of interaction introduced below can occur in all contexts of collaboration when the equipment is configured properly. Indeed, they are more generic modes of interaction which, in contrast to those described elsewhere (Sun, 1999; Beynon et al., 2003)⁸², should not be viewed in association with the underlying technical

⁸¹ What is not being considered is communication between modellers that can be carried out via email or other forms of communication that does not exploit or is not directly connected with the collaborative modelling environment.

⁸² The interaction modes that are associated with the DEM framework are based on the client-server architecture of the dtkeden tool, and therefore, are limited to a star-like communication network (cf. Sun 1999).

architecture of the tool (e.g. a client-server architecture).

Private

In the private mode of interaction, modellers construct their own models in isolated contexts (i.e. in their private workspace). Though collaboration between modellers may exist, there is no interaction through the computer-based model among the modellers (i.e. collaboration takes place outside the modelling environment). In EM, this means each of the modellers constructs their own computer-based model on separate workstations. As shown in figure 5.3, though there is an overlapping area of observation and are potentially overlapping parts in the model, the modellers may not be aware of that potential overlapping with other modellers' models.

In EM, this means that the modellers do not share any observables, dependencies or agents between their models. In other words, in the private mode of interaction, modellers are either in SMSA or SMMA scenarios (as described in section 5.1.2). As an example, a couple of students sitting at workstations a short distance away in a classroom may build their own jugs EM model without any interaction within the modelling environment. However, they may discuss their progress from time to time through speaking loudly or other tools (e.g. instant messengers) outside the modelling environment.

Similar private modelling situations can be found in traditional software development, where developers are working in separated workspaces and integration only take place outside the individual workspaces. de Souza et al. (2004) observed that the application programming interface (API) has dual roles in collaboration in the software development process. On the one hand, APIs facilitate collaboration during the decomposition process because i) they serve as contracts between stakeholders and developers, and therefore a larger system can be broken down into smaller pieces and each of the pieces can be constructed by developers independently; ii) they enforce the organisational boundaries between software developer teams (deSouza et al., 2004). On the other hand, APIs limit the information available to the developers during the *recomposition* process (Grinter, 1998; also cf. deSouza et al., 2004).

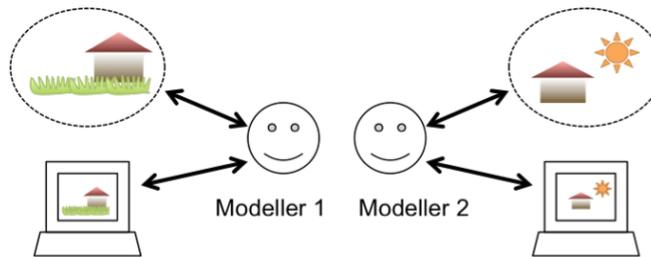


Figure 5.3 – Private mode of interaction

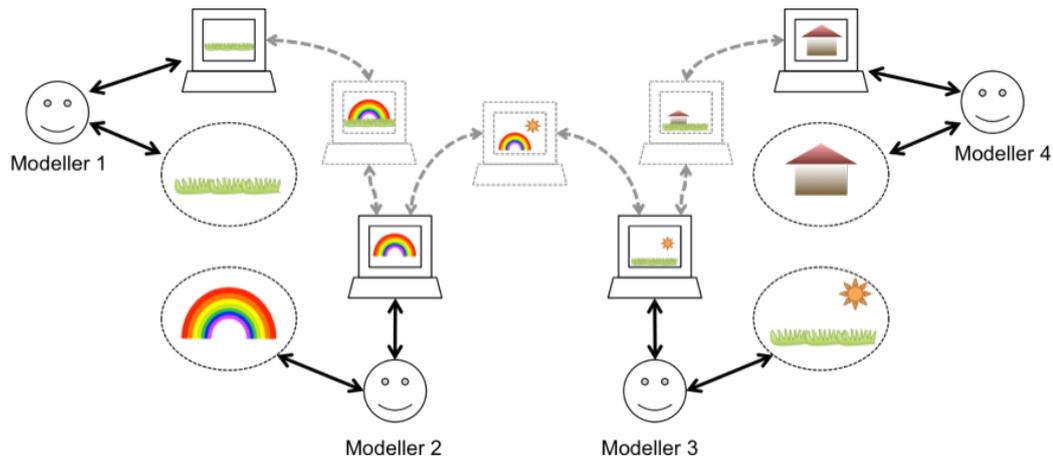


Figure 5.4 – Peer-to-peer mode of interaction

In the same sense, while the private mode of interaction may offer an isolated context for individual modellers to concentrate on their own model construction in an uninterrupted environment (as least in respect of the modelling environment), the private mode has little value when *recomposition* (Grinter, 1998) of individual models is required. In section 5.4, I will discuss how this issue may be overcome by practising an EM approach in the collaborative modelling context.

Peer-to-peer

In the peer-to-peer mode of interaction, modellers exchange parts of their model through “private channels” in the modelling environment (cf. figure 5.4). As Sonnenwald (1993) observed, peer-to-peer (or one-to-one) interaction often plays an important role in facilitating diverse perspectives in collaborative work. The term “peer-to-peer” reflects its fully decentralised characteristic. Such mode of interaction is commonly ad-hoc in nature, where interaction occurs spontaneously (i.e. on demand). Modellers are “connected” in pairs and each modeller may have multiple shared workspaces with other modellers. For instance, as

shown in figure 5.4, modeller 2 is sharing her model with both modeller 1 and modeller 3, but in two separate shared spaces. It is worth noting that the sharing need not encompass the whole model, and parts need not be the same. For instance, in figure 5.4, modeller 3 shares “the sun” with modeller 2, but “the grass” with modeller 4; and neither “the sun” nor “the grass” is the whole model of modeller 3 currently constructing. The sharing between modeller 3 and modeller 4 echoes the MMMA scenario as mentioned in section 5.1.2. In EM, the peer-to-peer interaction implies that common observables, dependencies or agents only exist in the shared modelling space between the modeller pair. There are no overall authentic⁸³ observables, dependencies or agents among all modellers.

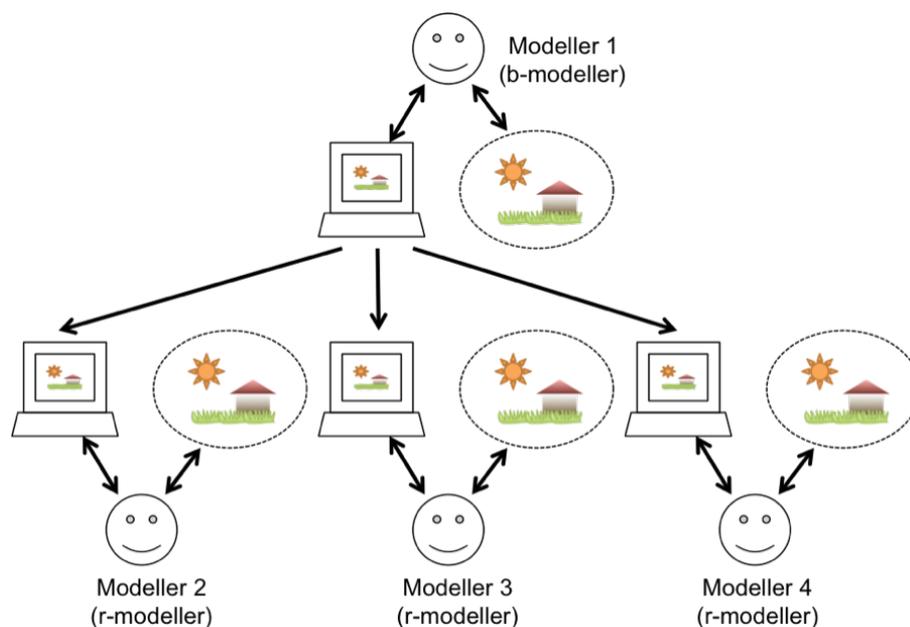


Figure 5.5 – Broadcast mode of interaction

⁸³ The word ‘authentic’ is used in the sense that is used in Sun’s (1999) thesis to refer to the instance of the observable that has the ‘objective’ value.

Broadcast

In the broadcast mode of interaction, modellers can be divided into two groups, namely the broadcasting modellers (referred to as *b-modeller* thereafter) and the receiving modellers (referred to as *r-modeller* thereafter). As shown in figure 5.5, the b-modeller broadcasts her model to all the r-modellers – all modellers are virtually seeing the same model through their workstation. Besides, all the r-modellers cannot modify the model and they can, in principle, only discuss the model outside the modelling environment. Because of this limitation, the r-modellers can be viewed as the subordinates of the b-modeller.

In the context of EM, the broadcast mode of interaction implies that the authentic observables, dependencies or agents are pushed from the b-modeller so that the r-modellers are not allowed to maintain private values for what they observed. In contrast to the broadcast mode associated with the DEM framework⁸⁴, the broadcast mode of interaction describes here is a mono-directional broadcast.

One example of the use of broadcast mode of interaction is in the classroom context, where the teacher (i.e. acting in the role of a b-modeller) demonstrates a pre-constructed model or constructs a model on the fly to the students (i.e. acting in the role of r-modellers), whether with or without feedback from the students (outside the modelling environment). One of the EM models, Virtual Electronic Laboratory (VEL)(EMPA: velShethDOrnellas1998), has exploited the broadcast mode of interaction, which will be discussed in detail in section 6.1. It is worth noting that modelling in the broadcast mode alone may not be considered to be “collaborative modelling” because the model in the public space, arguably, is merely the effort of a single modeller (i.e. the b-modeller).

⁸⁴ The broadcast mode in DEM is multi-directional and it allows individual modellers to have a private set of observables, dependencies and agents (Sun 1999; Beynon et al. 2003).

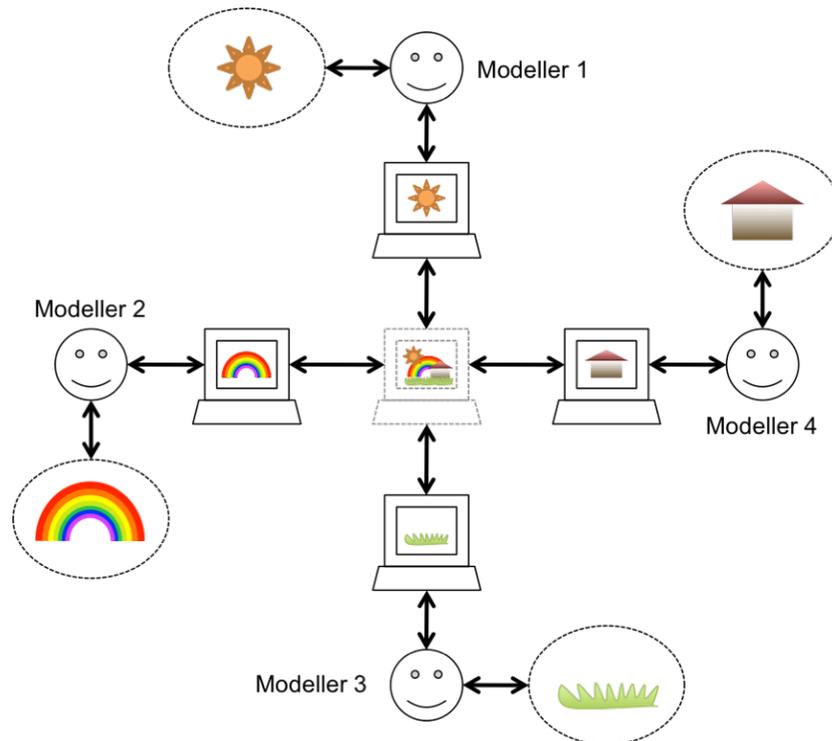


Figure 5.6 – Blackboard mode of interaction

Blackboard

The use of the term “blackboard” is similar to that described by Iain Craig (Craig, 1995) in his book *“Blackboard systems”*. The blackboard metaphor came from Newell (1962) in the context of group problem-solving activity (Craig, 1993). In the blackboard mode of interaction, modellers are interacting within the one and only one shared modelling space. Each modeller may freely contribute parts to the shared model based on their knowledge and personal experiences. As shown in figure 5.6, the shared model is composed from the parts from the individual modellers. Although individual modellers may only focus on their own parts on their workstations, the individual contributions are instantly integrated into the shared spaces. This resembles the situation where a group of students gather around a blackboard and sketch ideas, compose parts, or discuss the results on the blackboard at real-time.

In contrast to the broadcast mode, the blackboard mode can be thought of as multi-directional broadcast since it allows more than one contributor to the shared model. In contrast to the privileged mode (which will be described below), there is no “authentic

values” or access control to the model, i.e. everyone can add, delete, or change parts that are currently in the shared model. In EM, modelling in blackboard mode means that the modelling space will only consist of public observables, dependencies and agents – there will be no “private” observables, dependencies and agents in the modelling space. The blackboard mode of interaction plays a crucial role in many collaborative modelling situations, as it allows modellers to interact freely. To show how EM may potentially facilitate this mode of interaction in collaborative modelling a case study on the collaborative jugs model will be discussed later in this thesis (cf. §6.3).

Interference

As in the broadcast mode of interaction, modellers in the interference mode are divided into two groups, namely, the senior modeller (denote as s-modeller thereafter) and the ordinary modeller (denote as o-modellers thereafter). The naming of the modellers reflects a status difference within the group of modellers who carry out the collaborative modelling. As shown in figure 5.7, the communication between o-modellers will be screened and filtered by the s-modeller, who has a higher status or authority in the group. In contrast to the blackboard mode, the collective model may not consist of all the parts from individual models. The advantage of modelling in this mode is that it avoids incompatibility between contributions between o-modellers. The integration of individual partial models can be negotiated among the s-modeller and o-members of the group (i.e. democratic strategy), or through the existing organisation structure of the group (i.e. dictatorial strategy). However, not all modellers may be satisfied with this integration arrangement. For instance, not every component of modeller 3’s model is integrated into the shared model (cf. figure 5.7). Another disadvantage with the interference mode is that it requires full-time attention by the s-modeller. This implies that asynchronised collaboration is impossible.

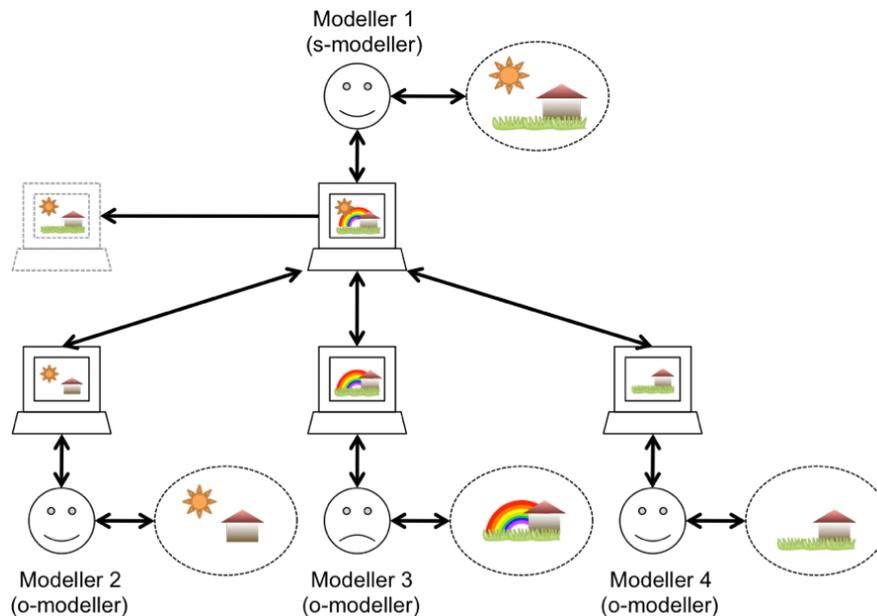


Figure 5.7 – Interference mode of interaction

In EM, modelling in the interference mode of interaction is associated with the situation that the collective model is composed through making explicit references to individual observables, dependencies and agents in the individual models, an intervention is carried out in the context of observation of the s-modeller.

One example of modelling in the interference mode is in the context of concurrent design (cf. Adzhiev et al., 1994a; 1994b), in which a single coherent account in the shared model is to be constructed from the diverse perspectives of modellers that require coordination and intervention from a more senior modeller. Such a mode of interaction may also be useful in relation to the creation of innovative artifacts, where such multi-faceted exploration between o-modellers is vital to improve the mutual understanding among the s-modeller and the o-modellers (cf. Sun, 1999; Sonnenwald, 1996).

Privileged

The privileged mode of interaction can be thought as a combination of the blackboard mode and the interference mode as described above. On the one hand, individual modellers (i.e. o-modellers) contribute their parts to the shared model as in the blackboard mode. On the other hand, o-modellers may carry out exploratory modelling in their private workspaces and are coordinated by the s-modeller as in the interference mode. In contrast to the blackboard

mode, modelling in privileged mode allows co-existence of diverse perspectives over the same area of interest, and the modellers may possess “ownership” of certain components in the shared model. For this reason, access to the parts in the shared model from individual modellers is not unrestricted, but based on their privileges. In contrast to the interference mode, the privileged mode of interaction makes fewer demands on the attention of the s-modeller. This is because the coordination is handled by the agreed protocol – i.e. the privileges of the modellers. This also implies that asynchronised collaboration is possible in the privileged mode.

To some extent, the privileged mode of interaction resembles everyday interaction in the objective world. For instance, in terms of EM, modellers may have different perceptions of an observable *isLightOn*. One modeller observes that the light is on because she is in the same room as the light is in, and, for the same reason, this modeller is also privileged to be able to switch the light on or off. The other modeller, in contrast, believes that the light is off because she cannot see any lights coming out from the room while observing from behind a dark curtain.

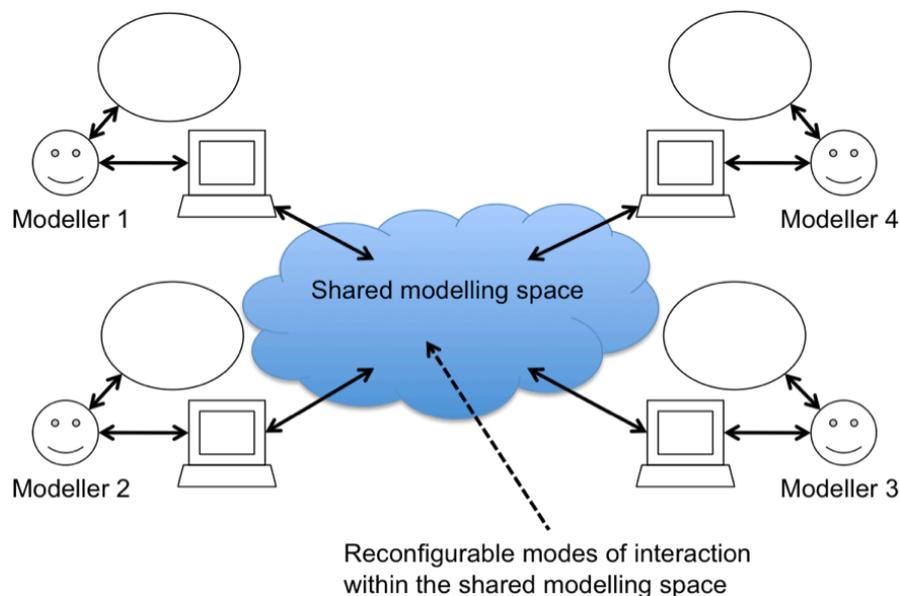


Figure 5.8 – Supporting diverse modes of interaction in collaborative modelling

5.1.4 The dynamic nature of collaboration

In the previous sections (§5.1.1 to §5.1.3), I have discussed different aspects of collaborative modelling. These include i) different degrees of engagement, ii) different relationships between modellers and agents, and iii) different modes of interaction. Whilst it may be possible to identify specific ways in which the modelling activity is configured with respect to (i), (ii), and (iii) over a short period of time, it may be a lot harder to characterise collaborative modelling that takes place over a prolonged period. For instance, in developing a ‘jugs’ model (cf. §4.1.1), the modellers could initially coordinate their individual observations, but later engage in collaboration when they counter overlapping interests amongst their observations. This could further develop into more intimate engagement which can be regarded as co-construction. Alternatively, the modellers could become less engaged if they employed some form of division of labour (i.e. might fall back into coordination activity). The relationships between modellers and agents might evolve in a similar fashion (e.g. from multiple SMSA situations initially to become a mix of MMMA and multiple MMSA situations) as might the mode of interaction (e.g. from interaction in broadcast mode, to peer-to-peer mode, then blackboard mode, and so forth). This is due to the fact that people interact in diverse ways for different needs. Furthermore, in a broader social context, people may engage in multiple collaborative modelling with various social groups. This dynamic, situated, and complex nature of human social nature of collaborative modelling motivates us to view the relationship among modellers in the collaborative process as a *cloud*⁸⁵. Figure 5.8 illustrates how the “cloud” might be placed among the modellers. On the one hand, the cloud metaphor captures the complexity and difficulty in properly accounting for collaborative modelling moment by moment. On the other hand, the cloud metaphor recognises the need for reconfigurable support to address different aspects of collaborative modelling, which include different degrees of engagement, different relationships between modellers and agents, and different modes of interaction.

⁸⁵ The cloud metaphor is borrowed from cloud computing (Weiss 2007), which emerged in the IT industry recently.

5.2 Why is Distributed Empirical Modelling not good enough?

Previous sections explained what is meant by *collaborative modelling* in this thesis and how EM might be practised in such context. In this section, I argue that the previous EM conceptual frameworks for distributed modelling and the tool support derived from these frameworks might not be good enough to support the interaction in *collaborative modelling*.

5.2.1 Historical development in Empirical Modelling for collaboration

In EM, the term collaborative modelling first appeared in the COMICAL project⁸⁶, in which the term was used to refer to collaborative EM with the distributed EM framework and tool. Previous research into EM (e.g. Adzhiev et al., 1994a, Sun, 1999, Wong, 2003) shows the potential to apply EM principles in collaborative contexts. For instance, Adzhiev et. al. (1994a; 1994b) explained how EM might potentially be practised in the context of concurrent engineering. In Adzhiev et al.'s framework, the complex conceptual design of an engineering product is repeatedly decomposed into smaller pieces, along the hierarchical organization structure, for individual modellers to deal with. Each modeller is responsible for the coordination and composition of the modelling of their subordinate modellers. Beynon et. al. (Adzhiev et al., 1994b) argues that the roles of the design agents (i.e. the modelling contexts of the modellers) have to be arranged in a hierarchical manner due to the need for resolving conflicts in the concurrent design process. Hence, EM is recursively practised at an individual level and coordinated at the collective level throughout the organizational hierarchy in relation to the concurrent engineering design process.

The lack of networked distributed modelling support for developing multi-agent systems (cf.

⁸⁶ COMICAL stands for "Cognitive Observation-Oriented Modelling for Interactive Computer-aided Learning". It was a project which set out to examine the potential of the Empirical Modelling approach to Computer-Assisted Learning (CAL) in UK schools in 1999. The project was funded by Warwick's Research Teaching Initiative (RTI). It included a workshop that was hosted in the Department of Computer Science at the University of Warwick in the summer 1999, and the participants of that workshop were mainly school teachers in the UK.

Beynon and Russ, 1994; Beynon et al., 1990) became one of the main research motivations for the development of Distributed Empirical Modelling (DEM). Sun (Sun, 1999) argues that research into EM has been mainly focused on modelling activity that is centred around “*an external observer who can examine the system behaviour*, but [such modelling activity] has to identify the component agents and infer or construct profiles for their interaction [prior to the modelling activity being carried out]” (ibid, p.77, italic in original), or what he referred as *S1-modelling*. Despite the fact that such a *S1-modelling* strategy is still useful in the context of *collaborative modelling*, Sun (1999) argues that a more pertinent modelling strategy is to enable the modellers to observe from the perspectives of the component agents, i.e. observing from inside, or what he referred as *S2-modelling*.

To formulate a framework based on EM principles better suited to a distributed modelling environment, Sun further derives two distributed modelling strategies, *E-modelling* and *I-modelling*, that combine *S1-modelling* and *S2-modelling*. Sun argues that such a combination of strategies is potentially more useful in the context of distributed modelling in general, and software systems development in particular.

E-modelling and I-modelling, in fact, are quite similar – both maintain a hierarchical structure among modellers, where subordinate modellers are led by a single supervising modeller in the hierarchy⁸⁷. The only differences between E-modelling and I-modelling are that:

1. In E-modelling, all modellers are observing externally, whilst in I-modelling, only the supervising modeller is observing externally; all subordinate modellers are observing internally.
2. In I-modelling, subordinate modellers are not only observing internally, but also able to “act as the agent from the perspective of an *actor*” (Sun, 1999, p.91, italic in original), performing what Sun referred to as *pretend play*.

According to Sun (1999), the DEM framework is based on ethnomethodology (Garfinkel, 1967) and distribution cognition (Hutchins, 1995). On the one hand, Sun (1999) argues that

⁸⁷ In the DEM framework, Sun (1999) called the supervising modeller the *S-modeller* and the subordinate modellers the *A-modellers*.

the pretend play by the subordinate modellers in I-modelling resembles two important beliefs in ethnomethodology: “each agent is capable of managing the world and of ‘being-in-the-world’” (Sun, 1999, p.91; Garfinkel, 1967). The modelling, therefore, is based on reflexivity, in which the subordinate modellers account for the agents’ interactions through reflecting on the interactions that they carried out on behalf of the agents (Sun, 1999). On the other hand, Sun (1999) argues that I-modelling resembles an environment for the subordinate modellers to interact with each other and with the artifact (i.e. the model pieces within the modelling environment) in a fashion that corresponds to social organisations such as are described by Hutchin’s (Hutchins, 1995) distributed cognition theory.

5.2.2 Issues with the DEM framework and its tool support

Since the introduction of DEM, a number of domain-specific conceptual frameworks have been built on the DEM framework. For instance, the SPORE⁸⁸ framework for requirements engineering (Sun, 1999), the participative business process re-engineering framework (Chen, 2001) and the framework for software integration and virtual collaboration in the financial sector (Maad, 2002). While DEM may have proved its potential in distributed modelling, it may not be good enough to support diverse modes of interaction and seamless transitions between different degrees of collaboration. In the rest of this section, I argue that the DEM framework may potentially hinder collaborative modelling in two aspects, namely, interaction and collaboration.

Interaction aspects

Flexible structure

To some extent, the two distributed modelling strategies that Sun (1999) described, i.e. E-modelling and I-modelling, are quite similar to the MMMA scenario described in section 5.1.2. Whether practising EM in E-modelling or I-modelling, there is always a supervising modeller to coordinate the contexts for observations and modelling of the subordinate modellers. This poses a structural constraint in the DEM framework which may limit its

⁸⁸ SPORE stands for “Situated Process of Requirement Engineering”.

potential use in wider collaborative work. Sun (1999) argued that this structural constraint makes it possible to synthesise Gruber and Sehl's shadow-box experiment, where the supervising modeller acts as the "experimenter" and subordinate modellers act as "observers". In this way, the supervising modeller can maintain full control of the knowledge construction process. For Sun (1999), the supervising modeller plays a crucial role in shaping the subordinate modellers' knowledge of the situation in DEM, though the supervising modeller may be "transparent" to the subordinate modellers in such process. Despite the merits of this configuration, the DEM framework has paid little attention to the collaborative modelling that may take place outside formal structured social organizations. Such collaborations are usually dynamic and fluid, and may involve unstructured groups and ad-hoc collaborations.

Besides unstructured groups, the collaborating group may already have an existing structure, both formal and informal. It is not often a good idea to impose a particular structure on such a group as it may disturb the group dynamics and lead to the tool becoming redundant (cf. Grudin, 1994a). Because the tool support for the DEM (i.e. dtkeden) is a groupware, its adoption and adaptation is subject to socio-technical issues in groupware (cf. §2.2.2).

Furthermore, distributed cognition emphasizes the stability and the reproducibility of a socio-technical system rather than its emerging properties or changes (Kaptelinin and Nardi, 2006; Béguin and Clot, 2004). It is a theory that focuses on well-structured and organized groups, which "places the most emphasis on coordination" (Kaptelinin and Nardi, 2006, p.221). The adoption of distributed cognition theory in the DEM framework further proves that it was not developed for *collaborative modelling*, but merely for coordinated distributed modelling.

Flexible modes for observation

In the DEM framework, the external observation is assigned to the supervising modeller, and each subordinate modeller is assumed to enact the role of one particular agent at any given time. There is no provision for the subordinate modellers to construe through making observation from an external perspective in DEM. Sun (1999) argued that external observation alone is not suitable for DEM. Therefore, the DEM was developed in a way that

does not allow the modellers to switch between external and internal observations.

In EM, agents and agency emerge and evolve during the course of the modelling process (cf. §4.1). Restricting a modeller to particular modes of observation and interaction with a particular agent restricts the modeller's ability to investigate the interactions between multiple agents and carry out the agentification process which is essential to EM (cf. §4.1; Wong, 2003). While this may be useful when refining the agents and agencies in the later stage of the modelling process, it potentially hinders the agentification process throughout the modelling process. From the collaborative modelling perspective, it is therefore inappropriate to frame the contexts for observation and for modelling through restricting the modellers to particular modes of observation.

Taking all these issues into consideration, I argue that the DEM framework is not appropriate for collaborative modelling where multiple modes of observation and seamless transition between these two modes of observations are essential.

Dynamic interaction and reconfigurable environment for interaction

In the DEM framework, modellers are forced to interact through the model. Sun (1999) argues that such configuration for distributed modelling "makes individual contexts combine with each other to create a social context corresponding to Hutchins's model of what actually happens in a human society" (ibid, p.102). Sun argues that only by interacting as being-participant-observer internal to the model and through the modelling environment will the modellers benefit from practising EM. In the other words, if the modellers have to interact and model in separate contexts, the advantages of enacting EM are largely reduced (Sun, 1999). After all, the conflict between agents will only surface through modelling in a common modelling space.

However, if modellers have to interact and construe in the same modelling space, DEM for collaborative modelling has to support diverse and reconfigurable modes of interaction, and seamless transitions between them. This is because human activities are situated (Suchman, 1987), and it is rather rare for them to stay in one particular form of interaction. For instance, in the Virtual Electronic Laboratory (D'Ornellas, 1998; Sheth, 1998), the students and the teachers may adopt various modes of interaction in different tasks

throughout the laboratory. However, the experimentation in the laboratory is a continuous activity. It would be unreasonable to expect the students and the teachers to restart a new modelling space when they move from one mode of interaction to another. Since DEM inherits a star-like hierarchy (as mentioned earlier), it neither allows modellers to switch between different modes of interaction (cf. §5.1.3) nor allows modellers to reconfigure the interaction between the modellers and agents (cf. §5.1.2)

Collaboration aspects

Bridging the public and the private modelling spaces with a single shared modelling space

One of the issues with the DEM framework in the collaboration aspects is that DEM does not make an explicit distinction between the shared modelling space and the personal modelling space. Consequently, there is no support in the DEM tool (viz. dtkeden) for seamless transition between the shared modelling space and the personal modelling space.

One may argue that the roles of the supervising modeller and the subordinate modellers have already been fixed in the DEM framework (i.e. I-modelling). It is then impossible for a subordinate modeller to become confused because the supervising modeller has already fixed the contexts for observation by the time the subordinate modeller starts her modelling. Furthermore, the global context simply does not exist if all the subordinate modellers are acting as agents internal to the model, looking from inside the agents. However, from a collaborative modelling perspective, the DEM framework does pose a challenge – the subordinate modellers may not be aware that they are actually modelling in a shared space until there are mysterious clashes of their model. Even then, subordinate modellers may still think such clashes are interventions from the supervising modeller rather than overlapping or conflicting definition from other subordinate modellers. Indeed, the modelling experience can be very frustrating if the modeller cannot tell which space her modelling is going into. One way to mitigate such an issue is to bridge the public and the private modelling spaces with a single shared modelling space (cf. Greenberg and Roseman, 2003), such that all modellers, both supervising modeller and subordinate modellers are all modelling and interacting in the same modelling space, and the contributions (i.e. model pieces) from individual subordinate modeller are visible to all other modellers. To some extent, interacting

within a single shared modelling space also stimulates individual modellers' "immediate experience" of the overall model.

Lack of support to awareness

In section 2.1, I mentioned five aspects of successful groupware, namely, awareness and coordination, articulation work, creativity, experimentation, knowledge sharing and knowledge construction. Since the DEM is the conceptual framework behind the distributed modelling tool – dtkeden – and the tool itself is a groupware, we expect the DEM framework to address these aspects at a conceptual level. In fact, the DEM does address most of these aspects, except awareness⁸⁹. Due to the fact that DEM is based on the I-modelling strategy (Sun, 1999), information about other modellers' constructs (observables, dependencies, and agents) is often hidden away. Such information is only disclosed to the subordinate modeller at the discretion of the supervising modeller when they believe that information may be relevant to the subordinate modeller's modelling situation at hand. Even when the information is released, it is released as if the action is taken by the supervising modeller due to the star-like network architecture; the subordinate modellers have no way to detect who is responsible for the change. This low level of awareness of others' modelling work may lead to potentially conflicting or incompatible model pieces when subordinate modellers are interacting in the same modelling space but their contexts of observation are highly overlapping (e.g. the modelling is at the collaboration degree of engagement and in the MMMA scenario).

5.3 How EM might support collaborative modelling

In the previous section, I have argued that DEM was primarily developed for distributed modelling. When collaboration and interaction is at the centre of concern, rather than merely building an EM model in a distributed environment, DEM does not seem to be addressing these concerns very well. This may be in part because more recent research has given us a better understanding of collaboration. For instance, collaborative modelling is more complex

⁸⁹ This issue was discovered in a series of pilot experiments (unexpectedly) prior to the collaborative modelling case studies, as I will discuss in chapter 6.

than distributed modelling because the collaboration it involves may be both remote and collocated and both asynchronous and synchronous, depending on the situation at hand. All these considerations motivate the question: “How might EM potentially facilitate collaborative modelling, in relation to different styles of collaboration?”

In this thesis, *collaborative modelling* is viewed as the core activity for groupware development. While the link between collaborative modelling and groupware development will further be examined in chapter 7, it seems appropriate to devote this section to study those aforementioned questions in more detail. Precisely, this section investigates how EM may potentially be practised in the context of collaborative modelling.

As I discussed in section 5.1, there are three important aspects in collaborative modelling. One of these, the degree of engagement in collaboration is particularly interesting in the context of this thesis, as it offers a holistic view of the overall *configuration* of the modelling activity that takes account of the intimacy of the relationships amongst the modellers, the activity, the context, and the artifacts of the collaborative modelling process. Consequently, the research question stated above can be refined as “How might EM modellers coordinate, collaborate, cooperate, co-construct, co-evolve throughout the EM process?” and in particular, “How might EM modellers develop inter-subjective *construals* collaboratively through the model building process?” Therefore, it seems appropriate to examine the potential of EM at different degrees of engagement in the context of collaborative modelling.

5.3.1 Coordination

As mentioned in section 5.1.1, when collaborative modelling is at the lowest degree of engagement – coordination – there may be only sporadic interactions between modellers, and plausibly, most of these are carried out asynchronously. When practising an EM approach, this implies that the modellers are mostly working alone in their private workspace, either in the SMSA or SMMA situation (cf. §5.1.2), and the coordination of the individual model-building activities may be done through tools that are external to the modelling environment. For instance, modellers can coordinate asynchronously via exchanging definitive scripts through tools external to the modelling environment, e.g. email or script sharing on a file server. When synchronous interaction is needed, modellers can

interact in the various modes discussed in section 5.1.3. However, due to the sporadic need to interact in coordination, modellers may prefer a peer-to-peer (ad-hoc) mode of interaction rather than the more sophisticated ones, e.g. interference or privileged.

5.3.2 Collaboration

When the degree of engagement in collaborative modelling is at collaboration (cf. §5.1.1), members of the team are bound together in a shared activity with shared resources. However, they may not have an explicit common goal for the modelling process. In this case, modellers may have to explore the same phenomena in the context of observation in different directions or from different perspectives. Therefore, the key concerns of such collaborative modelling activity are to facilitate diverse perspectives, to explicate different accounts, and eventually to come to negotiate a common unified perspective.

As mentioned in chapter 4, EM is an observational-based approach to modelling. Observation in EM is based on the modeller's subjective and personal experience of the situation being observed (cf. §4.1), and Hanson, a philosopher of science, has also argued that the observational process is personal and situated (cf. §4.2). Therefore, EM artifacts that are construed by individual modellers based on the same context of observation offer diverse perspectives. This satisfies the first concern – facilitating diverse perspectives. For the second concern – explicating different accounts: the observables, dependencies, and agents in an EM model offer a partial account of the situation being modelled and the modelling environment, tkeden, can be used to animate this partial account in different ways to reflect the experience of different modellers. For the last concern, modellers can negotiate for a common unified perspective through redefinitions in a shared modelling environment synchronously, e.g. in the blackboard mode of interaction (cf. §5.1.3). The purpose of these redefinitions can either be to add, modify, or replace “components” or “parts” in the EM model, and modellers can experience the differences between perspectives. All these potential styles of collaborative modelling will be demonstrated in a case study of cricket simulation in the chapter 6.

5.3.3 Cooperation

To some extent, cooperation can be thought of as “collaboration in a larger scale” in contrast to the lower degree of engagement of collaboration in the context of collaborative modelling. At this level of collaboration, people pursue a pre-defined shared goal – i.e. an explicit common goal in contrast to collaboration. For the purpose of productivity of the overall modelling activity, the larger modelling context is often broken down into smaller but interdependent tasks for individual modellers to tackle, i.e. division of labour. Meanwhile, individuals have to maintain awareness of other people’s modelling to avoid incompatibilities with others’ modelling and to improve the productivity of their own modelling. Therefore, the main concern in cooperation can be thought of as making the model-building activity easier through effective partitioning of the larger modelling context and integration of smaller individual pieces.

Although EM does not promote modelling cooperatively with a pre-defined goal, there is no reason why EM cannot be practised in such context. Sun (1999) suggested various strategies in which individual modellers can model cooperatively, where each individual modeller is assigned to a smaller context for observation. In *E-modelling*, each subordinate modeller act as “an external observer who observes the system as if from the perspective of a particular agent and can enact EM individually” (Sun, 1999, p87-88). In *I-modelling*, each subordinate modeller observes the system as an internal observer who plays the role of a particular agent, which Sun referred as *pretend play*. For Sun, both of these strategies enable a senior modeller to coordinate the subordinate modellers, both in E-modelling and I-modelling, in relation to the contexts of observation and to the scope of modelling. However, Sun (1999) argues that E-modelling is not suitable for the purpose of DEM, as the potential for *enacting EM* is diminished when subordinate modellers are forced to carry out EM in a context away from the one in which they normally interact with each other. However, in the context of this thesis, modelling through external observation is still considered within the scope of collaborative modelling, whilst both E-modelling and I-modelling are considered as particular configurations of the MMMA scenario in collaborative modelling (cf. §5.1.2). In section 6.1, modelling at the cooperative degree of engagement will be illustrated in the

case study of the Virtual Electronic Laboratory (VEL) project (D'Ornellas, 1998; Sheth, 1998).

5.3.4 Co-construction

When the degree of engagement in collaborative modelling comes to co-construction, the modellers are not only concerned with what to do and how to do it, but also with communicating why they are doing it. Modelling in co-construction is not only concerned with the artifact, i.e. the model, but also with the shared understanding of the shared activity, the shared resources, and the artifacts that are co-constructed throughout the model-building activity. As the shared understanding emerges, there might be adjustments to the shared goal of the modelling.

Gruber and Sehl's shadow-box experiment reveals that shared understanding among modellers of the situation being observed can be obtained through exchanging tentative constructs (or construals) of their personal experience (Sun, 1999; Gooding, 1990). EM is concerned with the modellers' immediate experience throughout the modelling process. As I discussed in chapter 4, EM artifacts are cognitive artifacts (cf. §4.1.2 and §4.1.3). What is constructed in the modelling process is not merely the artifact (i.e. the EM model), but also the understanding of the situation. For this reason, EM advocates continuous reinterpretation of the situation being observed through continuous interaction with the EM model and continuous observation of the situation. These characteristics of EM are well-matched with the need to facilitate the changing perspectives in co-construction, and potentially ease the establishment of shared understanding through interacting with a shared EM model within the same modelling space.

Due to the diversity of interaction in co-construction, collaborative modelling at this level may be carried out through different modes of interaction throughout the modelling process. For instance, modellers may interact in the blackboard mode at one point in order to maintain visibility of their interactions to other modellers and interact in the peer-to-peer mode or privileged mode at other time for other types of investigations. In respect of the relationship between the modeller and the agent (cf. §5.1.2), co-construction involves modelling in both MMSA and MMMA scenarios, where modellers switch between these two scenarios

seamlessly as their focus of attention shifts.

5.3.5 Co-evolution

At the highest degree of engagement in collaborative modelling, both the individuals' and the shared, understanding of the situation for modelling and of the artifact will co-evolve through the collective model-building activity. Meanwhile, the artifact itself will also evolve. Therefore, this co-evolution is multi-way. Consequently, the focus of support is on easing this co-evolution. One may argue that this co-evolution will happen anyway, regardless of the tools and the approach we are using in collaborative modelling due to our ability to adapt to less-than perfect situations. However, there are at least two objections to this idea:

- i. The first objection is that the referent for modelling and the context of observation may evolve on some occasions. In fact, this is exactly the case for groupware development, where the work that is supported by the groupware is ever changing throughout the development process. That is to say, in the context of groupware development, the referent for modelling and the context of observation for collaborative modelling is a "moving target".

The second objection is that the co-evolution between individual understanding, individual artifact, and individual activity does not necessarily trigger coherent co-evolution in the collective context. In this cases, the co-evolutionary support of the tool and the approach arguably becomes crucial to effective collaborative modelling. And whilst it may be hard to dismiss the argument against the need to support co-evolution in collaborative modelling completely, there are reasons for supposing that adopting an EM approach can make a radical difference, and in due course provide a pragmatic justification. In any event, as with the co-evolutionary perspective in technology development (cf. §2.2.2; and also Ackerman, 2000), it is our choice whether to round the edges for greater convenience and productivity or to tolerate the discrepancy of the tools, methodology, etc for collaborative modelling.

As mentioned in chapter 4, EM has flexible and open characteristics in relation to model building (cf. §4.1.2 and §4.3.5). Modelling in definitive scripts enables the modeller to explore different possible configurations of observables, dependencies, and agents to

represent the *referent*. From a holistic perspective, the modellers' understanding and the individual models co-evolve as the "continuous reinterpretation" takes place (as mentioned earlier in §5.2.4; also cf. §4.1). The intimate interplay between individual modellers' understanding and their individual model (or parts of the collective model) is similar to that suggested by Naur (1985a; also cf. §3.1). This eventually eases the overall co-evolution through the diverse interaction among the modellers through and around the artifact during the collaboration process. Indeed, EM does not presuppose a static context for observation nor a predefined goal in the modelling process (cf. §4.1.2).

To bridge the co-evolution at the individual level and the collective level, Sun (1999) proposed a framework (i.e. DEM) which enables collective co-evolution driven by individual co-evolution through what he referred as *evolutionary interaction* – modellers evolve the agents inside the model through playing the role of the agents and interact with other agents act as if they are the agents themselves inside the model. Apart from such "co-evolution from the inside", it is also possible to evolve in the scenario of MMMA through external observers or a mix of internal and external observers in a shared modelling space, in which modellers can evolve the agents from both inside and outside the agents. This eventually leads to co-evolution of modellers' understanding of the situation for modelling and of the artifact, both individually and collectively.