Chapter 3
Models for sharing representations

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Companion modelling implementation is based on a network of individuals and artefacts amongst which models occupy a special place. This chapter presents the various models developed in a companion modelling process for purposes of representation sharing. Designed as a way of understanding actual (reference) systems in which social and biophysical dynamics overlap, models represent the evolution of these systems and are used for organizing exploratory simulation exercises involving stakeholders in the reference system. Chapter 1 introduced the different purposes for using models in a companion modelling process:

– make heterogeneous viewpoints visible and open to debate
– question the coherence of these viewpoints and the consequences of their simulation in relation to the real world as lived by the participants
– propose a medium for exploring scenarios collectively through simulations in a virtual world.

There are different ways of translating multiple viewpoints to a reference system in models. This translation is based on conceptualizing the system studied to describe the share of reality perceived as useful by each stakeholder and culminates in specific artefacts being developed and computer techniques and situation simulation exercises (role-playing games) being mobilized. A brief introduction will explain the choice of MAS as a preferred method for representing the domain studied. This chapter will describe different model lines: domain models, conceptual models and simulation models. The knowledge extraction, abstraction, formalization, conceptualization and finally, implementation stages will be presented in succession. The use of simulation models as a medium for exploring future scenarios will then be developed before concluding the chapter with an analysis of the adaptability, complementarity and versatility of these models, characteristics that provide tremendous flexibility in implementing the companion modelling approach.

Introduction

The first section explains the choice of MAS as a main method of representing a studied domain based on actual agents from the reference system. The translation process from domain model to executable model (simulation model) via the conceptual model stage is then presented. Lastly, the elements used to characterize simulation models are detailed. These take the form of a purely computerized simulator, that of a role-playing game simulating the situation of stakeholders in the domain around the actual game media, or appear as a combination of these two extreme modalities.

Ways of representing reality

We view modelling as an explicit writing process in which knowledge and heterogeneous hypotheses are distributed in the same artefact, allowing them to function together. The resulting artefact is more or less capable of taking charge of unplanned interactions.

Adopting a constructivist conception of representations (see Chapter 1), we confine ourselves here to representations attempting to account for a given system, which are perceptions (viewpoints) of this system frequently designated as being 'the real world'. To represent it is to create hypotheses about that which seems to characterize it best based on a targeted objective. This involves breaking it down into building blocks so that these hypotheses can interact, then suggesting how to reconstruct it. We briefly review here a few possible structuring approaches from the many options, by giving slightly more detail on the MAS frequently used in the companion modelling approach. These structuring approaches are not exclusive and some work in progress is seeking to use them jointly.

We could, therefore, set out to represent stocks and stock flows. This is the dynamic system approach. It involves highlighting the flow regulation, control and action options and any retroactive loops. The system is described by a set of state variables (the stocks) and equations describing their dynamics (the flows). At stake is identifying what these stocks represent in terms of the system in play. It often involves energy, biomass, water, monetary units and so on. This type of representation is not particularly explicit about the stakeholders linked to these flows or the conditions for their intervention.

Game theory provides a framework for understanding these stakeholders and anticipating their choices by identifying their rationalities and decision rules strategically. It is a static type of representation: all possible interaction scenarios must be specified. The system is represented by a set of strategic stakeholders equipped with an objective function applied to this system. The dynamics of resources combined with these interactions are generally described less accurately.

The description as MAS sets out to conceive virtual worlds made of interacting entities with the explicit aim of reconstructing simplified, yet relevant, situations with respect to the question dealt with. It involves identifying the active entities (agents) who play a decisive role in managing the system, specifying their management entities and their degree of autonomy and stating how they interact with their environment and the other agents. These entities can be objects, items in the landscape, individuals or groups of individuals (e.g. farm, village, institutions, etc.).

MAS are thus understood here as a metaphor of reality (i.e. social, biological and physical) as a set of interacting autonomous entities located in an environment, given an objective and with representations of their environment (Ferber, 1995). Note that defined thus as a representation type, MAS make no reference, even implicit, to computer science. In our field of application, the entities make decisions dealing with resources. They therefore interact both with the resource medium and with the other decision-making entities with which they are in contact. Numerous experiments have shown that MAS are well suited to simulation in the domain of resource management (Bousquet *et al.*, 1999; Bousquet and Le Page, 2004).

From reality to its representation as a simulation model

Companion modelling envisages developing and using models, which represent a form of understanding of a reference system, as a means of sharing simplified representations of this system. The vast majority of models are dynamic, in other words, they include explicitly hypotheses and rules linked to changes in the reference system over time. The modelling process produces concrete, operational tools used for the simulation, the exploratory activity that refines the forms of comprehension of the reference system and draws new knowledge from them by giving effect to long-term visions discussed and analysed collectively. Allowing stakeholders collectively to see the progressive changes in the system under listed conditions and practices stimulates in particular their ability to comprehend the mechanisms of decision-making processes (theirs and also those of other participants). In addition, inciting reflection on the mechanisms responsible for outputs exhibited by the simulations helps to make explicit certain hypotheses that would otherwise remain hidden in a conceptual model.

The translation chain for the reference model into one or a family of executable operational models has already been described (e.g. Fishwick, 1998). Drougoul and his colleagues proposed a detailed analysis of the translation chain in the specific framework (which interests us here) of the design process for simulation models based on agents, by considering the roles of thematician, modeller and computer scientist for each of the three stages they describe (Drougoul *et al.*, 2003). The thematician defines the domain model by using the semantics he associates with the reference system. As the thematician's specifications do not provide direct transcription into an executable model, the modeller adapts the domain model into a more formal model known as the design model (or conceptual model); its purpose is to clarify the concepts used, check coherence and delete potential ambiguities. The conceptual model is the result of a co-construction process that closely links the thematicians and modeller. Ultimately the conceptual model could be transcribed by the computer scientist into an operational model or a simulation model. This stage is too frequently ignored, which compromises any chance of understanding the impact of purely computational specific features on the emergence of artefactual structures in a simulation (see the section 'From the conceptual model to simulation models: Implementation' below).

Whereas Drogoul and his colleagues argued in favour of a clear separation between the roles of thematician, modeller and computer scientists (firstly, because each role demands specific skills and secondly, because the need to transfer elements between role sponsors means they must be formulated clearly) (Drougoul *et al.*, 2003), in practice, companion modelling is frequently seen as an accumulation of roles. Thus, the modeller will also create the operational model or will also help to develop the domain model by contributing his thematic knowledge. The advantage of this accumulation is less online loss in communicating between roles and greater continuity in interacting with the thematicians. Companion modelling is also an original way of opening up the roles of thematician and modeller to the stakeholders of systems represented.

Presented as successive stages (see Chapter 1), the modelling process, focusing on converting the domain model into the simulation model, seems implicitly linear. Alongside the standard process of refining a conceptual model for a certain time before moving on to the construction phase for an operational model (that can be manipulated to produce exploratory simulations), which is a direct and faithful translation, ComMod sets out to make possible and facilitate the comings and goings between the collective construction framework of a non-frozen conceptual model (a range of conceptual models) and the forming of lines of operational models (see Figure 3.1).

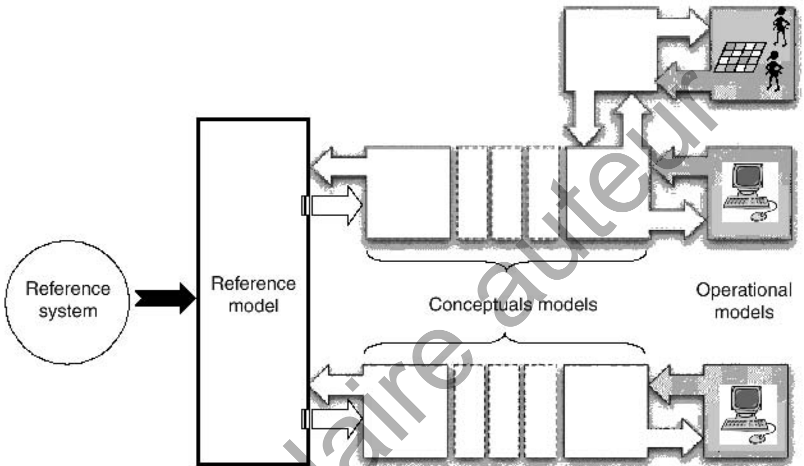


Figure 3.1. Model lines starting from the same reference model, with each line ending in an operational model (role-playing game or computer simulation model) (inspired by Treuil *et al.*, 2008).

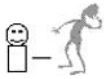
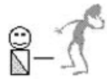
Simulation models based on miscellaneous types of agent

Our conceptual models therefore are MAS. Converting a conceptual model based on the MAS paradigm into a simulation model makes the implicit choice of translating each conceptual entity into a computational agent, which can be classified according to the nature of its decisions. Table 3.1 groups the various types of computational agents used in companion modelling implementation.

When all the decisions of an agent are made by a human being and there is no computerized go-between, the computational agent is a human agent type (commonly called a player). When this same decision is relayed by an avatar (computerized representative of a human agent) with no decision-making autonomy, the term used is simple composite agent. Conversely, when the decision is made entirely by the autonomous avatar (all the decision-making processes are created automatically by executing computerized instructions), the term computerized (or virtual) agent is used. The intermediate case of a human agent relayed by a partial decision-making avatar is called a hybrid composite agent.

To characterize an agent-based simulation model it is important to consider all the agents in its make-up. Two major types can be clearly distinguished: (i) simulation

Table 3.1. Types of agent based on the split between human decision and computer-specified decision.

Nature of the decision	**100% human**		**Intermediate**	**100% computerized**
Typology of computational agents	Human agent = player	Simple composite agent	Hybrid composite agent	Computerized agent = virtual agent
				
	No avatar	Non-decision-making avatar	Partial decision-making avatar	Autonomous avatar

models based exclusively on human agents, commonly called role-playing games; (ii) simulation models based exclusively on computerized or virtual agents. A whole range of situations exists between these two extremes where some decisions are human and others are computer-specified (see Figure 3.2). The term hybrid agent simulation model covers all these intermediary situations.

Alongside the specification of computational agent decisions, the computer is often an effective medium for taking charge of a certain number of other functions unambiguously constitutive of the conceptual model representing the social and ecological system studied. The computerized medium is, therefore, only a component of the simulation model (one of the elements characterizing its structure) and not a computer model *per se* used jointly with another type of simulation model. The five main functions of a computer medium in agent-based simulation models are as follows: (i) inputting decisions by human agents; (ii) calculating agents' performance-related indicators (actions);

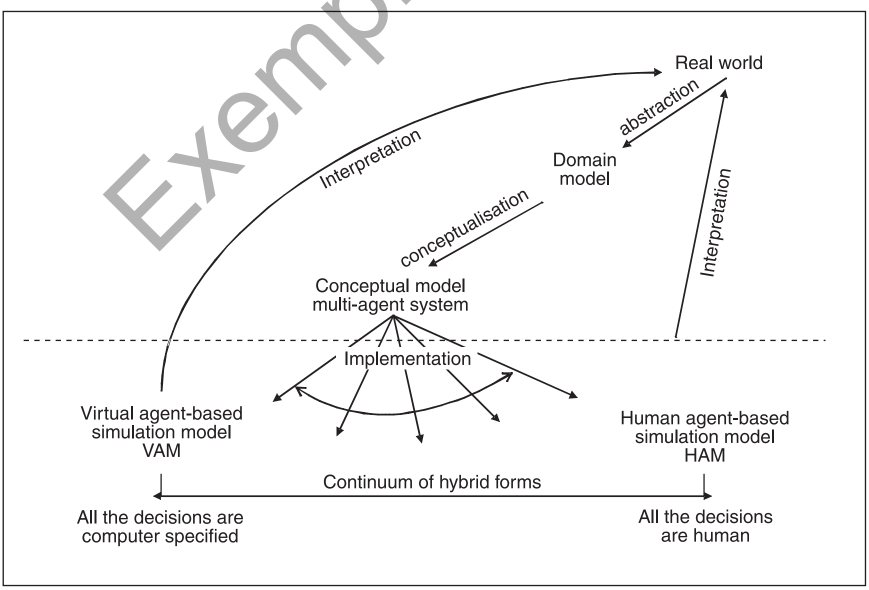


Figure 3.2. From real world to the implementation of agent-based simulation models.

(iii) simulating the resource dynamics; (iv) displaying the space (i.e. state of resources, positioning of agents, any viewpoints of this space specific to each type of agent); (v) specification using computer language of agents' decisions.

We shall use the commonly used term 'computer-assisted role-playing game' to designate the human agent models calling on at least one of the first four computerized functions listed above. The generic term 'role-playing game' will be reserved thereafter for the simulation models where decisions are all human (including computer-assisted role-playing games) or essentially human (some hybrid agent models). Conversely, by considering the last function relating to the computerized decision specification as decisive, the hybrid agent models where the decisions are essentially computer-specified will be classified with the virtual agent models in the category 'computerized simulation model'.

The analysis of 63 simulation models developed in the 27 case studies analysed shows firstly that computerized simulation models and role-playing games take equal shares and secondly, that the role-playing games are frequently supported in some way by the computer (see Figure 3.5).

Box 3.1 – The development of models used in the Nam Haen (Nan) case study, northern Thailand.

Context

In Nan province, northern Thailand, the government wanted to preserve forest resources in the upper watersheds by establishing a national park. Setting up the park boundaries generated tensions between the officers of Thai governmental agencies (i.e. Forest Department and National Park) and two village communities (ethnic tribes) who feared that agriculture and the gathering of non-timber forest products would be prohibited in the reserved area. Stakeholders' perspectives were integrated into five versions of the same simplified representation of the system under study, derived one from another. These tools were combined to foster the development of a communication platform used to explore collectively and assess prospective scenarios.

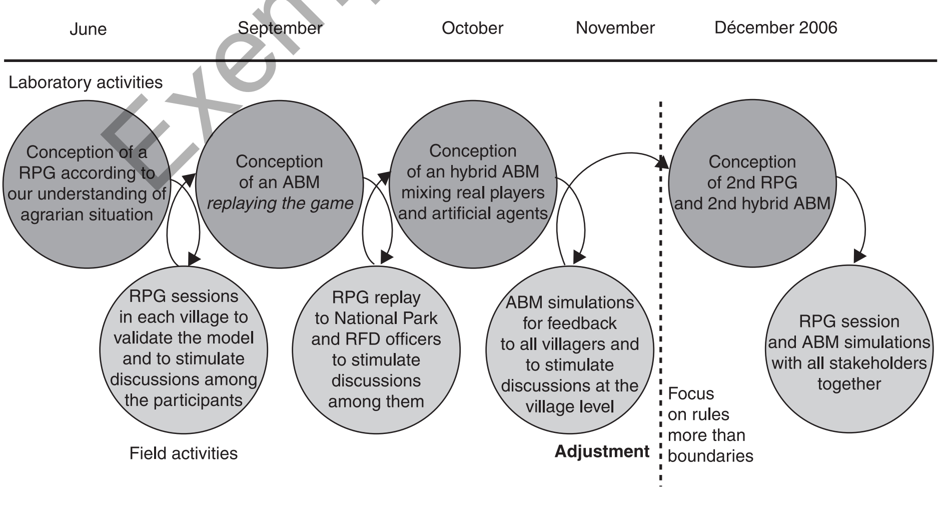


Figure 3.3. Chronology.

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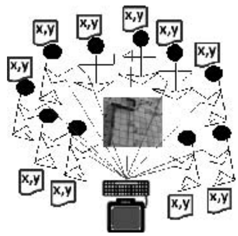
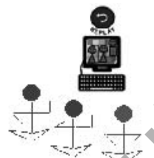
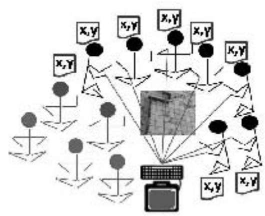
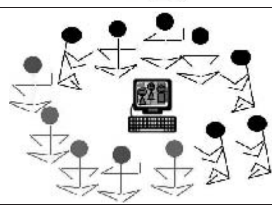
Version (changes compared to the previous version)	**Objective of the participative simulation workshop**	**Structure of the participative simulation workshope**	**Computer support and its functions***
First role-playing game *(representation of the agrarian system brought by the research team)*	In each village, promote discussion among 12 farmers playing their own role		Excel i. yes ii. yes iii. no iv. no v. no
« Replay » of first RPG (computer agents reproduce players' decisions)	Showcase to National Park officers the principles of the RPG and the outputs of the 2 gaming sessions		Cormas i. no ii. yes iii. yes iv. yes v. yes
Hybrid computer simulation *(simplified choice of crops)*	In each village, enlarge the group of involved farmers to disseminate information to a larger audience (3 players with 9 computerized agents)		Cormas i. yes ii. yes iii. yes iv. yes v. yes
Second role-playing game (the game board represents a wider space)	All the stakeholders together are able to talk about hot issues and to envision possible options fot the future		Excel i. yes ii. yes iii. no iv. no v. no
Autonomous computer simulation	To explore and discuss the scenarios identified		Cormas i. no ii. yes iii. yes iv. yes v. yes

*Functions of the computer:
i. Inputting decisions by human agents
ii. Calculating agents' performance-related indicators (actions)
iii. Simulating the resource dynamics
iv. Displaying the space (state of resources, positioning of agents, any viewpoints of this space

Figure 3.4. Comparison of the five versions of the model.

In practice, the adaptive nature of companion modelling produces a wide diversity of simulation models, not only in type but also in their use and association method. To illustrate this point, Box 3.1 (see page 74) presents the successive versions of the model designed and used in the Nan case study (Thailand): not just one but a family of simulation models (all referring to the same conceptual framework) were mobilized. A useful method of tracing changes in models and revealing their filiation is to position them in the same table based on the typology summarized in Table 3.1. We shall present a few examples in the last section of this chapter to illustrate how the diversity of methods to interlock and associate various models makes implementing exploratory simulations extremely flexible. Before that we will detail the abstraction and conceptualization processes by presenting the methods and tools used for each one.

Knowledge extraction and abstraction: from the reference system to the domain model

Repeating the terminology of the previous section, the first stage is to identify real relevant agents, in other words, make up the domain model. This stage involves pooling the questions and viewpoints from all the 'thematicians' made up of the researchers and stakeholders involved in this stage of companion modelling. This pooling, because it is contradictory, involves mutual learning of the viewpoints of others and changes in questions.

Formulating a question and a framework for the modelling process

The work starts by formulating a question structuring the viewpoint in which the thematicians will interact to develop the domain model. The framework comes from previous phases in the companion modelling: previous modelling cycles, 'command' from part of the stakeholders in the system or an investigation of a question originated by some of the researchers. One method of initiating the process is to compile the general impressions of the stakeholders who have been invited to participate using a general formulation such as: 'what do you think of such and such an aspect linked to such and such a resource (its management) in such and such a portion of space?'. For example: 'what do you think of the changes in the bluefin tuna population in the Mediterranean?'. It is to be expected that each response refers to a change recently noted (trend or event) and at the same time corresponds to a specific point of view suggesting a sort of appreciation of this change, for example: 'the species is threatened with extinction'; 'fewer [fish] have been caught over the last five years'. For some stakeholders, these changes will be perceived as negative, for example, environmentalists and tuna fishermen, whereas others could take a positive view, for example, sardine fishermen. The confrontation of various responses nevertheless reveals a common character over and beyond the expression of different sensitivities, for example, 'population numbers are dropping'. The model thus considers itself as a means of exploring the combinations of factors that reproduce this characteristic. The framework can be restricted by targeting precisely from the start a certain type of factor, for example, the traditional tools for fishery regulation such as quotas or reserves, which justifies not taking other factors into account, known nevertheless for their influence in reality (e.g. climate change). 'Everything equal elsewhere', what matters is the availability of a means of comparing effects of chosen factors specifically to be explored.

The first representation of the reference system, called the domain model, is a medium used to gather and assemble the knowledge of the thematicians involved in the modelling process. Based on the assumption that a thematician expresses their knowledge spontaneously, partly tacitly and in disorganized fashion, techniques must be implemented so that they can reveal it, specify and make it as explicit as possible so that it can be 'captured' and formalized during a process also involving a modeller. We call this eliciting knowledge, based on a combination of two operations – extraction and formalization.

Eliciting knowledge

There are many eliciting techniques. For example, monitoring the process where an individual, considered an expert in a particular domain, is placed in a simulated situation to resolve a problem and is asked to explain the actions he undertakes, or analysing transcriptions, which involves a lexical analysis, analysing a piece of writing or an interview transcription, thereby identifying and organizing all the elements constituting knowledge of a domain.

Applied to companion modelling, eliciting techniques are a chance to identify and formalize the knowledge of stakeholders in the systems represented, their reasoning methods, their decision-making rules or their strategies. However, these techniques have been developed for use by experts in a well-defined, controlled environment close to the one encountered in a laboratory experiment. We have developed our own eliciting techniques to transpose the methods of eliciting knowledge to the specific context of companion modelling (an uncertain, fluctuating environment difficult to delimit). We review three of them.

Note that these eliciting techniques sometimes call on formalisms in varying stages of development, whereupon they refer, at least implicitly, to preconceived conceptual entities acting as frames for the occasionally collaborative formalization of knowledge. We shall then consider that the work of conceptualization sets out to conceive these frames whereas the work of abstracting or eliciting sets out to 'instantiate' these frames (in knowledge engineering, this is the difference between defining an ontology and populating an ontology). It is not of course always possible to detect these two modelling work phases: in a collective workshop (with thematicians), where defining conceptual entities is not stabilized and open to discussion, conceptualization and abstraction will be closely linked, with abstraction used directly to test the conceptualization, which changes on the spot. Most of the time the workshops are turned towards one or other option but it is sometimes difficult to make a distinction, as seen in the ARDI case (see below). However, in that case it is stated clearly that the discussion does not cover the nature of entities and it is, therefore, more a question of elicitation.

Extracting knowledge from an interview transcription

The principle of this technique is to carry out an initial series of interviews with stakeholders from whom we hope to elicit knowledge and to analyse the semantics of interview transcriptions, in order to extract the elementary objects making up their knowledge (individual or collective). Then we reconstitute the logic of all this knowledge (called the cognitive model by some), often as an entity-relationship type diagram. The two phases in this approach, acquiring verbatim accounts during interviews and extracting knowledge from these transcriptions, are linked and equally important.

Although acquisition is confined to a given subject, for example, the collective management of water in a given perimeter, the social and environmental interactions addressed are such that it is often impossible to predefine the scope of the domain to be treated before the interview. Therefore, the open interview technique, based on an interview guide made up of neutral, open questions, is the most appropriate. In addition, the representation of a stakeholder and the actions he undertakes depend on the context in which he finds himself when he is being interviewed (Suchman, 1987). The interview must, therefore, be sited in its action context to be able to capture the empirical knowledge of a stakeholder. For example, to identify how a farmer represents water management systems, the interview should be held on his plot of land as he is irrigating it. The interview can also take place at several places in succession, for example, during a field visit (Abel *et al.*, 1998). Under this same logic of contextualization, it is advisable to start the interview with subjects relating to the activities or events in progress. Thus, if you wish to identify how a farmer represents his interaction with the environment, interview him on his plot and start with questions about his agricultural practices on this plot, before moving on to the links he sees between his practices and the environment. Lastly, do not forget that the quality of the acquisition depends on the more or less direct method in holding the interview (conversational or question and answer) and the relationship of trust between the interviewer and the interviewee. The interviews are then recorded and transcribed word for word for the extraction phase.

The extraction phase involves identifying in the transcription and recording (e.g. highlighting) all the words or semantic expressions relating to the concepts linked to the domain studied. The identification is then repeated for the other types of knowledge, namely, the processes, rules and relationships. Lexicographic analysis software can be used to facilitate this work (Dray *et al.*, 2006). This software encodes semantic expressions and analyses semantic networks, but identifying concepts, rules and relationships cannot be totally automated. The results of the extraction phase are largely dependent on the various types of knowledge, also called knowledge objects (Newell, 1982), which you have chosen to identify. There are various extraction structures or grids that cross-reference knowledge objects and semantic expressions (Table 3.2 is one such example).

Table 3.2. Cross-references between knowledge objects and semantic expressions (Becu *et al.,* 2003).

Knowledge objects	Semantic expression
Concept (object, person, etc.)	Equivalent to names: ‘forest’, ‘river’, ‘soil’
Process (operation, activity)	‘Build a house’, ‘fish sardines’
Attribute and value	Attribute: ‘cost’, ‘age’; value: ‘120 kg’, ‘heavy’
Rule	‘If…, whereas…’, ‘… up to …’
Relationship	Equivalent to passive verbs: ‘… is part of …’

Extracting knowledge by situation simulation exercises

Eliciting through a situation simulation exercise involves asking a thematician (who is frequently a stakeholder in the system represented under the companion modelling approach) to explain his projected actions under the various situations presented to him. This technique is used to elicit tacit knowledge from the person by stimulating introspection, which is the ability to raise awareness of vague or dissonant areas between emotions, thoughts and actions, thereby making his representations more coherent (Ferber and Guérin, 2003). Various situation simulation techniques can be used (e.g. story, photo slide show, role-playing game, etc.).

Thus the playable stories technique (Becu *et al*., 2005) only uses one situation simulation exercise per story. The story is divided several times reproducing, for example, the various moments in a crop-growing season. At each point, the facilitator orally describes the situation context (e.g. economic, climatic and social context of a growing period) and asks the stakeholder (sessions can be individual or collective) to explain the activities he would embark on based on this context. The session continues by alternating context description by the facilitator and description of activities undertaken by the stakeholder. In this technique, the actual extraction of knowledge (i.e. the transcription of semantic expressions into knowledge objects) is simultaneous with the stakeholder describing the activities undertaken. The information extracted is presented to the stakeholder on cards on which are written, for example, the name of the entity or process, or as photographs. As the session continues the information is assembled in front of the stakeholder who watches the domain model being constructed. Under this process the stakeholder can intervene directly in constructing the domain model (to enrich or correct interpretations made during his presentation), as in the participative construction of the diagram.

The role-playing game, another situation simulation technique, can also be used to extract knowledge. In this process, acquisition is made by direct observation of player behaviour during the session. Observers (normally several) of the role-playing game note the various actions undertaken by the players and the game situation in which the action has been undertaken. At this stage it is not stakeholder knowledge that is extracted but their actions in a given situation. It is only subsequently, during individual or collective debriefings, that the knowledge applied by the stakeholders to undertake their actions is elicited. To achieve this, each player is asked to explain why he embarked on such and such an action in the game and the information he used to reach his decision. In this way stakeholder introspection is simulated and his tacit knowledge elicited.

Extracting knowledge by constructing diagrams

The knowledge we seek to extract does not only cover knowledge objects viewed separately from each other. It also applies to knowledge on the relationship between these knowledge objects. Drawing diagrams is both a means of eliciting this type of knowledge in the interactional structure of the reference system and a first attempt at the domain model. It seems to us that the domain model corresponds more or less to this first abstraction stage, which could be summarized to advantage as a simple entity-relation type diagram, with the resource(s) and selected stakeholders positioned in it, and where each relationship between stakeholders and between a stakeholder and a resource is signalled by arrows labelled with a verb. This informal format based on 'natural' terms (no semantic restrictions or modelling jargon) provides a first visual glimpse of the model's constituent elements and their interactions, with the advantage of it being easy to comprehend by thematicians who have never been involved in modelling.

This means creating hypotheses for a given question on the elements of the world that are of importance in dealing with it. The three phases traditionally proposed in stakeholder analysis methods can be considered in succession here: (i) stakeholder identification; (ii) differentiation and categorization of identified stakeholders; (iii) specification of relationships between stakeholders. It is essential to consider during each phase the relevance of the planned choices by referring to the question raised. A resource is at the heart of the question considered in the majority of companion modelling implementation experiences. In practical terms, it seems relevant not to abstract this resource during the initial stakeholder identification phase.

Thus, as suggested by the ARDI methodology developed by Étienne (2006), the stakeholders can be categorized according to the more or less direct nature of their actions in the resource and for each type of stakeholder, the nature of the management entity specific to his action can be stated. There is a whole range of tools for use in specifying in a more or less structured fashion the relationships between stakeholders (e.g. as a matrix made up of + and – signs to signify the positive and negative influences between the stakeholders taken two by two).

Figure 3.5 gives an example of this type of diagram created as part of a modelling exercise for a case of disputed use in the Causse Méjan grasslands. In the diagram, the

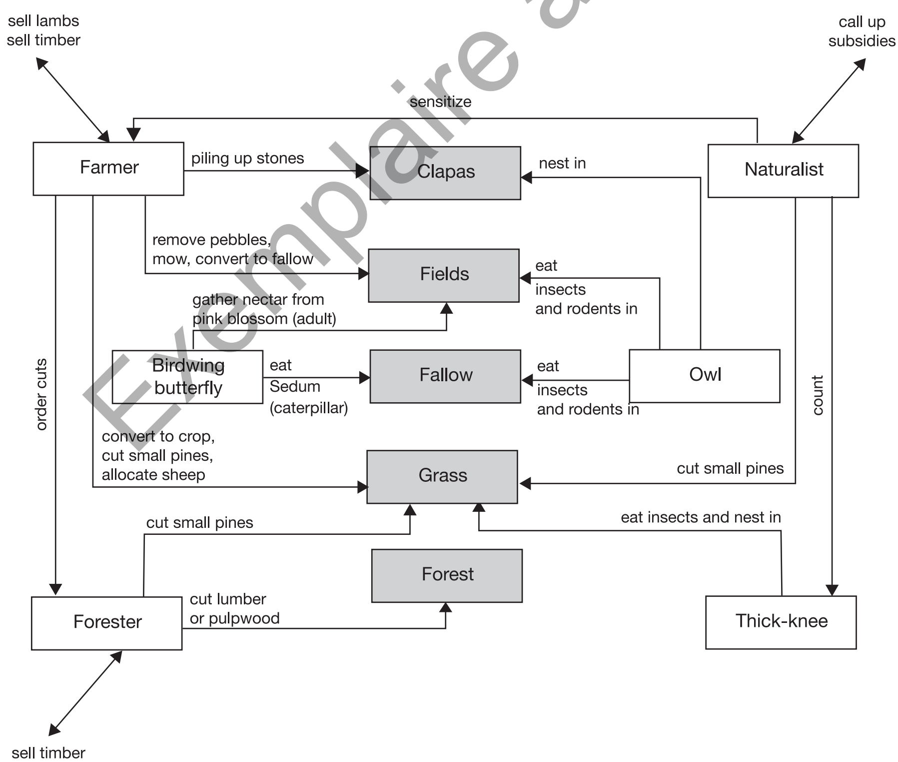


Figure 3.5. Sample conceptual diagram showing the domain model and the relationships between entities (Étienne, personal contribution) (Causse Mejan case study).

entities considered as the main stakeholders are shown, as well as the resources and also the special case of a passive entity (pebbles). At this stage, reflecting on the nature of entities gives little reward. The aim is to communicate, by presenting as simply as possible, an understanding of the key elements in the operation of the system concerned. Any other format fulfilling this function can be envisaged. Even if the format used is not very formalized, compliance with a few major underlying principles will greatly assist in comparing different versions suggested by several groups working in parallel. It is especially advantageous to implement this first phase in the conceptualization stage collectively, with participants who can be stakeholders in the system, scientists, decision-makers and so on. Comparing the various versions produced is a first step towards sharing representations.

This stage ends by stabilizing the domain model relating to an agreement at a given moment between the participants on the basis of cross-checking areas and cross-references between the various representations in the study domain. It is important to highlight any inconsistencies, contradictions, divergences and singularities remaining in these representations and to agree on how to deal with them, with possible and non-exclusive options including:

– avoiding the issue: the domain model is restricted to what has been agreed
– seeking a negotiation-based compromise
– using scenarios underlining and exploring 'disputed' areas (Dray *et al.*, 2006), or taking charge of inconsistent viewpoints when agreement is lacking in an examination to decide between them, such as a common observation in the field
– uniting viewpoints by limiting them to those not generating inconsistencies.

Formalization of knowledge and conceptualization: from the domain model to the conceptual model

Once the domain model is set, the conceptualization itself can start. Although formalisms, usually simplified, are frequently used from the first stages of abstracting the domain model, one or more formalisms must be strictly adopted for the conceptualization phase, which describes fully the different aspects necessary to convert it into a simulation model. Conceptualization, therefore, involves specifying the various components of the domain model in the selected formalism(s) and stating the different aspects, especially dynamics, to achieve a full description. Just like the abstraction, the conceptualization can be participative, in which case the processes are often closely linked. However, it can also be semi-automatic. We shall see lastly the large families of entities and processes found in our conceptual models. It is important to ponder the nature of entities and processes when seeking to conceptualize, as it is the way to relate them to available generic concepts.

Formalisms for conceptualization

A formalism is a formal expression method based on a set of words obeying rules and conventions (called formal grammar or syntax) and underlying semantics. The most frequently used formalisms to conceptualize models in the ComMod processes are as follows.

– Mathematical equations (e.g. for a biological process like the growth of a resource the logistical equation could be chosen). They are used to describe and specify particular processes in the evolution of certain entities.
– Pseudocode, a language close to natural language, resorting to elements in logical syntax (if, whereas, etc.) and a stabilized lexicon to designate entities, attributes and actions. It has the advantage of being easy to use in collective groups, including lay groups, whilst imposing a certain discipline in respecting the specific language of a given group and to a given moment in the life of this group.
– UML, which offers a stabilized grammar (unlike pseudocode) and which is, therefore, understood by all who know it, whether or not they took part in constructing the model. UML can formalize an object-oriented model as well as an agent-based model. It proposes in particular a panoply of diagrams (called 'views' used to present a conceptual model from different angles), such as class diagrams to describe the model structure as a set of connected entities, activity diagrams to present the behaviour of entities and transition-state diagrams to characterize the dynamics of changes in stages (Le Page and Bommel, 2005). Although creating UML diagrams can often be arduous, the aim is to achieve clear diagrams comprehensible to all, even those who have not taken part in the conception, which can be the case of the computer scientist who will be in charge of implementing the conceptual model.

The conceptualization process

Sequence of a standard conceptualization process

The conceptualization process normally comprises the following activities, which must not be seen as distinct and sequential as they are more often interlocked and iterative.

(i) Model structure specification: 'translation' of domain model entities in the chosen formalism. What are the entities? What are their relationships (which entity 'knows' which other and from which viewpoint)? What are their characteristic properties and the main actions they can perform? This phase is normally a chance to group the entities with similar behaviours by defining the most generic entities. In this case we talk about generalization, in which the match is called specialization. It is at this stage also that elements from previous modelling work can be usefully reused (e.g. generic social simulation models) or include elements from the thematicians' theories (thus the theory of agrarian systems is based on a typology of farmers according to a certain number of criteria that could be used to specify an abstract 'farmer' entity). By analogy with knowledge engineering, this phase may be compared with an ontology construction phase (Bommel and Müller, 2007).

(ii) Specifications of dynamics specific to the entities: intrinsic resource dynamics, operations capable of being performed by one entity (behaviours) and influencing its evolution or that of the entities to which it is connected, decision-making mechanisms mobilized to choose the behaviour according to the present state of the entity and the context (its environment). The mobilization of elaborated decision-making mechanisms is normally specific to social entities.

(iii) Lastly, specification of the ordering over time (scheduling) of these processes during a simulation time step.

During this conceptualization work, it is important to maintain a vocabulary that belongs to the domain modelled. The diagrams produced are basically intended for thematicians so that they can understand, grasp and criticize them.

Participative conceptualization

In most cases, the workshops that could be qualified as participative modelling are simply elicitation objects. The media are used by participants to explain how they perceive their system or simply to help them in reaching agreement. We talk, therefore, about participative conceptualization or conceptualization workshop when the stakeholders and thematicians are actually involved actively in the conceptualization work, be it in defining the formalism or conceptual models or when translating from the domain model. Ubon Rice Seeds case study is an example of co-conceptualization with local experts: under this application, both researchers and regional development stakeholders genuinely worked together to design the UML diagrams. The conceptual model of role-playing games used in the first phase of the study is based on this (Vejpas *et al.*, 2005).

As a general rule, from the moment both the stakeholders in the reference system and the thematicians working to understand this system are involved, it is virtually impossible to separate abstraction from conceptualization. The two mechanisms are closely linked and part of the same process. By relying on a formalism to remove ambiguities, this in fact involves systematizing the description of the model from different viewpoints, by gradually refining the domain model.

Within the framework of participative conceptualization workshops for a model that unites researchers and experts in the domain in an exercise of interdisciplinarity, the modeller proposes a formalism (often UML) to translate the domain model(s) into a conceptual model. His role is to facilitate the translation of concepts conveyed by the experts. Despite the existence of tools (e.g. computerized tables or simple blackboard or post-its) for use by all participants in modifying the model directly, the modeller is frequently the 'pencil holder' who coordinates the discussion in an attempt to incorporate and synergize the concepts. The formalism must, therefore, be comprehended as a language for bringing the disciplines closer together. Morel (1979) expressed this over 30 years ago: 'this is why collaboration between physiologists from all horizons on the one hand and computer scientists and biometricians on the other will remain necessary and desirable for many years to come. But to be fully effective, this collaboration assumes that the people involved in both camps are both taking a part of the path which too frequently separates them. It is in fact essential for each individual to know how to express himself in a language accessible to his partners, if only to comprehend fully the limits and possibilities of each other's respective approaches'.

Considering UML as a tool for interdisciplinary dialogue is also recognizing with Morand (2000) that 'the diagram is at the heart of the cognitive process, not teetering on the brink'.

With the reference system stakeholders, the participative modelling workshops can be considered more widely open: the stakeholders are asked to take part in constructing a representation according to a predefined and normally little discussed 'grammar', such as in the ARDI methodology developed by Étienne *et al.* (2008c), described above.

Conceptual model entities

The reference to MAS representation mode quite naturally gives food for thought, in terms of description, on the entities of the system to be modelled – stakeholders and objects – and how they act and interact. Compared with the domain model development phase, it is a question here of determining the conceptual entities that will be useful in representing the entities considered as part of the domain model. Remember that the model objective is essential, as this overview is useful for anyone encountering the model for the first time to understand why certain aspects of the system studied have been ignored (Grimm and Railsback, 2005).

Whether or not an entity will be translated into a class of the model is, therefore, a choice made at this level. The choice will also be made at this level as to whether a group is represented as a single entity or as a composition of agents.

Distinction can be made between different types of entity in the conceptual models. It can be useful to question the nature of the entities modelled as this can help in regrouping and encouraging conscious reuse. Various criteria can be used to distinguish between entities, but the breakdown we present here is the one normally used in the companion modelling processes and reproduced in the Cormas modelling platform.

The social entities, sometimes called agents, represent individuals, groups of individuals or institutions involved in resource management. Their role is normally to manage and/or exploit the system's resources, communicate with the other social entities and act on and/or receive spatial entities and other physical objects. The social entities are the bearers of decision-making abilities and thus of cognitive structures. These cognitive structures can be more or less advanced and depending on the question asked, there are reusable concepts in the multi-agent computer literature, be it in the perception, imitation and learning or intentionality abilities of social entities. In role-playing games, human players directly use their own cognitive abilities to make decisions, only constrained by the rules of the game.

The models we use include a spatial medium almost systematically. This medium is made up of entities (e.g. plots, regions, rivers, etc.), which configure the space and structure the network of spatial interactions. These spatial entities are also sometimes management entities linked to each type of actor, each one with a vision of the space specific to their type of activity.

The other model entities are physical, biological or intangible. The resource entities are a class apart from the others. These entities generally follow specific rules for their distribution and regeneration (e.g. water cycle, population dynamics, evolution and transmission of genetic traits). In computerized simulation models, these functions are often derived from simplified disciplinary models. In role-playing games, the same functions are frequently used as modules to support the game. It may happen that in abstract role-playing games, physical artefacts are used to simulate resources dynamics, such as marbles used to represent water flowing in (Lankford and Watson, 2007). The evolution of these resource entities relies on their interactions with social entities (e.g. intakes, modifications, exchanges, relocations, etc.). Reversely, the perception and management modes of social entities are focused on the dynamic of these entities.

The models can include entities representing other physical objects capable of being manipulated and/or exchanged by the social entities or acting on the resource entities. This wide category can group concepts as diverse as infrastructures (dykes) or money as well as communication media. The physical objects can curb the model's interactions in all circumstances.

Lastly, a final category is formed by the communication entities. This covers intangible elements (e.g. information, knowledge, beliefs, emotions, etc.) explicitly shown in the model as they make sense for the social entities and as they manipulate and exchange them. These communication entities are conceptualized most of the time as simple 'messages' containing a contextualized piece of information (e.g. information about water levels on plots in SHADOC, information on seed requirements and availability in Ubon Rice Seeds, etc.). However, it can happen that the information exchanged by the agents needs to be structured and differentiated better, whether socio-technical (technical itineraries) or psychological (emotional states). This type of entity is associated with agents using differentiated information to advance their representation of the world, their emotional states and to influence and possibly mislead the other agents. This is often the case of models addressing resource management problems from the angle of diffusion and impact of beliefs in society (diffusion of innovation or solidarity). Note also that the communication protocols under which these entities circulate (e.g. centralized diffusion, diffusion by mutual agreement, diffusion within social networks, etc.) have a strong influence on the operation of the system. It is often a topic for investigation in different scenarios for models showing information.

From the conceptual model to simulation models: implementation

One of the specific features of companion modelling is to encourage the development of several operational models referring to the same conceptual model (this is detailed below). In all circumstances (role-playing game or computerized simulation model), a simulator is developed to 'run' the model. Implementation accounts for this operationalization phase of the conceptual model in a concrete tool.

First, we deal with questions relating to time management and the choice of order in which the model entities are activated. For computerized simulation models in particular, these aspects have a significant yet frequently ignored influence on the behaviour of the simulated system. The practical aspects of manufacturing simulation tools are then addressed. A special place is given to spatial simulator media, essential tool components dealing with resource management issues and targeting shared representations. Finally, the three-way calibration-verification-validation is discussed by considering the specific features of companion modelling.

Managing time, ordering agents and ordering actions

Whereas, as we will stress, computerized time management forces a certain number of technical constraints that must be controlled when implementing a computerized simulation model, practical time management when using role-playing games also imposes constraints. Unlike a virtual agent, a human agent very quickly gets bored with repetitive activity. A role-playing game session must be thought out to ensure a ludic side with no down time. The number of time steps in a role-playing game session will inevitably be less than the number of time steps potentially implemented by a computerized simulation.

However, there must be enough to produce something decisive in the game and the period represented by a time step must remain relevant to the processes underlying the resource dynamics. From this point of view, it can prove useful to couple the role-playing game with a computerized simulation model (Barreteau and Abrami, 2007).

In computer science, time is either driven by events (the system manages an agenda) or by a clock (the time is segmented into regular time steps of identical length; this is called discrete time simulation). Both approaches have strong and weak points, but it is widely held that the discrete time approach considerably simplifies the development of the simulator and the understanding of a simulation sequence (Treuil *et al.*, 2008). This explains why this time approach is systematically adopted in companion modelling.

We have already pointed out that the simulation horizon (i.e. total number of time steps) relates directly to the definition of the question asked. This dimension is normally determined before considering the granularity (i.e. length of a time step) of the time, which in turn depends on the periodic intervals of all the dynamic processes in play. The granularity is normally chosen as equal to the shortest periodic interval.

The stakeholders in a reference system operate simultaneously. In a computer, the virtual agents who represent them are activated sequentially. Similarly, the sequence of elementary actions executed for each agent at each time step is sequential. It is especially important to specify clearly the chosen ordering rules when the model is implemented as they can have a tremendous impact on the simulation results.

Spatial media

The analysis of 63 simulation models developed under the 27 case studies reveals that space is omnipresent in these models: 90% of them have spatial representations. The representation of space is obviously computerized in computerized simulation models, which account for half the simulation models (see Figure 3.5). Spatial representation is generally not computerized in role-playing games (74%), despite the vast majority being computer-assisted (see Figure 3.5). In this case, space is represented by a game board that can take several forms. Three-dimensional blocks are one possibility when the land relief is a major component to be considered (e.g. Mae Salaep, SugarRice or Ubon Rice Seeds), more or less virtual maps representing a realistic space, such as a catchment area, the territory of a park or several municipalities (e.g. Nîmes-Métropole, Kat Aware, Méjan or Pays de Caux), more or less abstract regular grids (e.g. Radi, Lingmuteychu, Lam Dome Yai, Ouessant, etc.) or pictures fixed to the wall to outline an irrigated perimeter (e.g. Njoobaari, Larq'asninchej). Even when a computerized representation of space is provided, a game board is still frequently used during a role-playing game session. This association is complementary in certain cases: all participants visualize the two media, each one contributing specific information. Thus in the AguAloca case study, the game board localizes the hydrographic network and the pumping points (arches/nodes network), whereas at the same time the players can see the same space on the computer monitor from different viewpoints (e.g. soil occupation, municipalities, under-catchment areas). In other circumstances, the various spatial media are allocated to different types of players. Thus, in the MéjanJeu role-playing game, the farmers only had a local view of the space (close-up of their farm) as a printed map, whereas at the same time the naturalists and foresters could consult viewpoints of the entire space directly on a computer monitor.

Implementation

Implementing role-playing games involves identifying, if necessary manufacturing if they do not already exist, and preparing the game media. A game medium is an element that delivers information. A good medium is the result of a frequently difficult compromise between stimulating the ludic aspect and using user-friendly tools whilst avoiding excessive technology and timescales. It is also important to give thought to the form most suited to the type of information that has to be transmitted. Thus for money or material flows, pawns, post-its and notes can be used. 'Chance' cards and dice can be introduced to bring the hazards into play (note that it is sometimes important to be able to control the hazard so as to reproduce the same conditions, especially when you want to be able to compare game sessions). Sheets or *aide-memoires* can be planned to impart information at the start of the game, leaving them available during the game session.

In the case of computerized simulation models, the computer is the principal equipment used to construct the operational model and the computer programming languages are used to 'encode' the model as a list of instructions that can be interpreted by the machine. Several options exist.

– Specific programming: all aspects delegated to the computer must be encoded from scratch. The advantage is total control over the translation chain; the disadvantage is the time spent in reprogramming things that had already been programmed.

– Targeting a specific software program to take charge of a precise aspect (e.g. a geographical information system (GIS) software programme is well suited to representing and analyzing a space).

– Only using a single software program to integrate all the 'encoding'. This software is qualified as a 'generic platform'. A certain number of generic platforms have been developed specifically to facilitate the implementation of the computerized simulation model, but a commercial software program like a spreadsheet can do the job: this is true of the SylvoPast role-playing game developed by Étienne (2003).

The advantage of using a generic platform for implementing a computerized simulation model is unquestioned today. The main reasons are as follows: (i) the generic nature of numerous components (e.g. the space representation module); (ii) the availability of facilities providing efficient implementation of experiments with the model (e.g. launching simulation batteries by specifying the variation ranges for a set of parameters, displaying indicators, etc.); (iii) constitutes an applications library, a source of inspiration for modellers who are not computer scientists.

Cormas[1] (Bousquet *et al.*, 1998), a generic platform developed by CIRAD since the mid-1990s to facilitate computerized agent-based simulation model implementation applied to resource management, is used frequently in the implementation of companion modelling. One of the major strengths of Cormas is its reliance on the Smalltalk programming language; modellers who are not computer scientists find this very easy to use and it makes it easy to reuse extensions already developed in other models. NetLogo[2],

1 http://cormas.cirad.fr/indexeng.htm
2 http://ccl.northwestern.edu/netlogo/

Swarm[3] and Repast[4] are among the other widespread generic platforms developed to implement computerized agent-based simulation models.

When the reference system combines several levels and dimensions, a model can help in making representations specific to each level or dimension coherent. In Chapter 10, the two main options are presented: either the goal is to integrate the diverse representations into a single one or to coordinate them. In terms of generic platforms, the first option requires an integrative tool, whereas the second one requires a toolkit providing tools suitable for each level. An integrative generic platform should also provide functionalities to support the activities specific to all the sequential stages of the modelling process. Mimosa[5] is seeking such an ambitious objective, combining a simulation kernel based on the discrete event system specification (DEVS) with tools to specify ontology and an extensible set of formalisms.

Calibration, verification and validation

Calibration

Calibration involves adjusting a model so that its outputs correspond to the expected values (most frequently, a set of empirical data). If not, the model is adjusted by modifying the values of certain parameters. This process is similar to adjusting a measuring instrument using a calibration standard. The parameters selected for this adjustment have a slightly peculiar status. In practice, a parameter is chosen that has both a significant influence on the model outputs (two distinct values produce different results) and for which the value is not known with any certainty. Certain elements of the model must be modifying if adjusting the parameters is not enough to obtain satisfactory results. This results in a more or less in-depth re-examination of the operational model or the design model or even the domain model. Calibration is no longer the issue at this stage it is more a new learning curve through modelling and evaluation.

The design of a role-playing game used for situation simulation exercises sometimes uses calibration to give the model the best chances of achieving its specific objective, namely stimulating exchanges between participants. As the original question for implementing the approach normally causes a problem for certain stakeholders represented in the model, a suitable calibration will be sought to reach a marked situation provoking reactions from participants and stimulating discussion after a few simulation time steps.

Verification

Verification sets out to judge the correct performance of the simulator, in other words, the faultless implementation of a model in a machine. Put another way, it involves knowing that the model is constructed correctly: 'building the model right' (Balci, 1988). However, how can one be sure that the simulation outputs flow only from mechanisms that are thought to have been developed in the model? There are many ways of revealing artefacts related to programming or calculation errors, to approximate management of simulation time and interactions between agents or to any other erratic behaviour of the

3 http://www.swarm.org
4 http://repast.sourceforge.net/
5 http://sourceforge.net/projects/mimosa

simulator unrelated to the conceptual model it is supposed to express. Miscellaneous small defects or approximations can be amplified into more significant errors, which risk having a strong influence on the overall behaviour of the system.

For relatively complex models, such as those simulating the operation of socio-ecosystems, ensuring the total absence of bugs is virtually impossible to achieve. Thus, according to Gilbert (2008), the number of bugs in a computerized simulation model follows a negative exponential function: after a rapid drop, it never reaches zero, even after a long debugging process. This observation compromises the fundamental scientific principle of reproducibility of results. Several recent studies seeking to reproduce published simulation results have confirmed this problem (Edmonds and Hales, 2003; Rouchier, 2003). Now aware of this, researchers using computerized simulation models are joining together to produce recommendations intended to make it easier to discover recalcitrant bias and bugs (Gilbert, 2008).

Models developed under companion modelling are often very simple and are sometimes called toy-models. They are not necessarily designed to be reused outside the context for which they have been specially designed (throw-away models). These characteristics tend to render them less sensitive to the point raised earlier; not that they are less prone to bugs or artefacts, on the contrary, but more because the consequences of these errors are not decisive in relation to the approach. ComMod does not seek to suggest finely calibrated, expert solutions but to trigger dialogue between the participants to the point where the model can be considered as a pretext, an intermediate mediation object. These models can, therefore, be modified during use (not just the parameter values but potentially also the structural elements) by inputting suggestions from participants during the participative simulation workshops. These modifications are applied 'on the fly', without taking the time for a conceptual rethink or to check for the introduction of any computational bias. It makes the models difficult to communicate to anyone other than the people who modified them, which raises the problem of their transferability.

Validation and validity

According to Balci (1988), validation consists in comparing the behaviour of the model with the 'actual' system it is supposed to represent. When this comparison is satisfactory, the model is validated. To put another way, we are seeking to know if we built the 'right model' (Balci, 1988). A 'correct' model is, therefore, often perceived as a model which 'tallies' well with the data. Of course, depicting simulation results with variables that can be measured in the field is an essential dimension in model validity. However, it is not enough to consider this dimension alone. Without even mentioning accidental correlations, there are a vast number of theoretical or practical problems in comparing outputs from a model with empirical data (Amblard *et al.*, 2006). Good correlation with data can stem from an external factor not taken into account by the model. The model can also exhibit results consistent with data, whereas the modelled mechanisms are found to be totally erroneous. In addition, if the data used to calculate this correlation have also served to calibrate the model, referring to this single criterion to declare its validity is nothing short of deceitful.

As companion modelling comes under the tradition of constructivism, knowledge built up by the modelling experiment do not in this context form either normative principles or predictive theories. They take the form of 'generic proposals', intended to 'enlighten the reader, arouse his thought processes and his questioning and stimulate his imagination and his creative action' (Avenier and Schmitt, 2007). Thus, the know-how is not 'validated' in the traditional sense but 'legitimized' by the consistency of the construction method and by the subsequent use made of the co-designed know-how.

It is nowadays widely acknowledged that the concept of validation makes sense within the scope of a given modelling approach: it is useless to discuss it in general (Pala *et al.*, 2003). Companion modelling, considering that the issue tackled by the model is not definitively framed from the beginning but rather that the modelling process contributes to enlighten it, relates to 'soft operations research'. The model is used as a support to debate the issue along a continuous learning process. According to Checkland (1995), in such a context, the validity of a model relies mainly on its ability to generate learning. As soon as the model seems 'credible' to users and moreover, the users assess that they are learning through its design and use, then the model is validated. This kind of 'social validation' is quite different from the standard vision that strictly relates the quality of a model to measurements of its distance to the reference system it is representing.

Simulation models to explore collectively possible futures

Chapter 2 discussed the human dimension in coordinating participative simulation sessions (and more especially situation simulation exercises using role-playing games) and detailed the roles to be shared by the facilitation team members. We present here a supplementary viewpoint that describes in practical terms the implementation of collective scenario exploration workshops based on role-playing games and/or computerized simulation of a virtual world.

Setting up the simulation workshop

Prior to introducing the model to the participants, a participative simulation workshop starts with a general presentation of the context governing it, to provide elements of response to the following questions. Who took the initiative to implement the approach and with what goal? Who selected the participants and based on what criteria (e.g. stakeholders whose actual activities are represented in the model, legitimate stakeholders for representing a group, taking relationships between stakeholders in everyday life into account, etc.)? What is the specific goal of the workshop and which programme will be used to move it forward?

In the case of role-playing games, configuring the space in which the workshop will take place must be thought out based on the spatial characteristics of the reference system, so as to position the players in identified locations, that is, key places with a clearly defined status (e.g. market, public meeting place or private place) and thus reproduce certain major properties like neighbourhoods and distances.

Introducing the simulation model

Presenting the model is a difficult phase. It must be short to allow participants to become actively involved as quickly as possible, but it must at the same time provide a whole range of information on comprehending the model structure (i.e. representation of the space and types of agent making up the model), the decisions to be taken by the players in each turn or actions by the computerized agents at each time step, the indicators available to account for the consequences of these decisions and actions, the resource dynamics and lastly, the scheduling of the simulation (periodic intervals for processes, period representing a time step and total number of time steps simulated).

The amount of information communicated to the participants during this model introduction phase must be minimal but nevertheless enough to trigger the learning mechanisms efficiently according to the principles of active pedagogy (see Chapter 9). The information is often asymmetric in role-playing games: the participants received elements specific to their role, which are not divulged to others.

To ensure that the model is understood correctly, a role-playing game session can act out a 'dummy run'; for computerized simulation, checks can be made to see if the participants anticipate correctly the gradual changes in state (in step by step mode) of the simulated entities. The complete disentangling of a first scenario can then be envisaged.

Identification and formulation of scenarios

Participative scenario planning stimulates the creativity of participants through simple tools (e.g. short stories, diagrams, etc.), which envisage the trajectories towards possible futures of a socio-ecological system (Peterson *et al.*, 2003; Evans *et al.*, 2006).

In the context of companion modelling, 'scenario' is understood more as an operating mode for the simulation model or more precisely a set of factors that are going to modify its operation: a certain stakeholder behaves differently, certain ecological dynamics are disturbed, a certain variable of social or economic clamping is changed. Changes in how interactions are organized are also frequently envisaged (e.g. new exchange systems, new negotiation protocols).

The scenarios are often defined collectively when the simulation results of a first scenario are discussed, which instigates suggestions for alternative scenarios. It can happen that the first, so-called 'baseline' scenario (established with reference to the current situation of the system studied) has been put together by the workshop designers as a starting point for the exploration process.

The role-playing game technique is effective in generating scenario proposals but far less so in exploring them. During a game session, producing a time step (game round) in fact requires a great deal of time. Whilst taking care to maintain the ludic nature, a method must be found to link the game rounds sufficiently well to get close to the relevant simulation horizon in terms of the question asked and the evolution speed of the processes represented. Here is where computerized simulation really comes into its own.

Exploration and observations

An advanced exploration of the model's properties is always useful in an experimental approach; it ensures its robustness and measures its sensitivity to the various parameters likely to be mobilized to define scenarios. When run a great many times the model produces thousands of observations. It is important, therefore, to conceive experimental designs so as to produce the targeted information at minimum cost. The use of simulation platforms like Cormas provides access to a whole set of functionalities, which helps considerably in producing this experimental design.

One of the basic principles of companion modelling stipulates that the exploratory simulation of contrasted scenarios, by structuring the exchanges between involved stakeholders, lets them validate the interactions between the different representations and system dynamics integrated in the model. The simulation takes part in a co-learning process (or mutual learning between participants and workshop coordinators) in the system studied, strengthening the interaction with, and between, local stakeholders (see Chapter 9).

Indicators and viewpoints to monitor changes in the simulated system

Indicators used to monitor changes in the simulated system and compare the proposed scenarios are calculated from the model variables. In agent-based models, these variables correspond to entity attributes, be they spatial, active (agents) or passive. A given attribute may be considered directly as a relevant indicator, but functions calculated from several attributes to develop the most synthetic indicators can also provide the basis. During the various stages in the approach, a panel of indicators mentioned as relevant by certain participants is gradually compiled and supplemented. These indicators, which correspond to what each stakeholder is accustomed or wishes to consider in his activities, orchestrate their perception of the virtual world.

As an agent-based model is often made up of a significant number of entities, it is tedious to use graphs alone to monitor changes in all the indicators. A practical means of observing the indicators in a whole range of entities is to define the viewpoints specific to each type of entity as a function of visualization, which allocates an image of a specific shape and colour to each value or interval of values of the indicator. Applied to all entities defining the spatial medium of the computerized simulation model, called here 'viewpoint' and corresponding to a 'theme' in the GIS, it offers a dynamic spatial representation of the simulation on which can be superimposed the dynamic representations of situated entities.

Thus under the ComMod implementation in the Causse Méjan (Étienne *et al*., 2003), a series of viewpoints was constructed to facilitate understanding of the process of grassland encroachment with pine trees by making a clear distinction between the physiognomic (the pines are seen in the landscape) and functional (the pine seedlings have become established in the plot) aspects. Another was constructed to localize the heritage issues of fauna, flora and the landscape to produce a synthetic representation. Another accounted for the work carried out and its localization, as seen by either the silviculturist or the naturalist. Some viewpoints have sought to convey a particular aspect as, for example, changes in the risk level of encroachment from adult pine trees located on the ridges.

There are several ways of providing the observable elements in a simulation to the participants. The entities represented according to different viewpoints like the graphs can be printed or displayed on a computer monitor (so that the information can be specific to the participants it is intended for) or projected directly in the room (information shared by all the participants).

The diverse viewpoints are presented to participants who observe (computerized simulations) or experience first-hand (role-playing games) changes in the simulated system. Participants find it easier to grasp the viewpoints when, under identical conditions of simulation for the same scenario, they comprehend them at the same time as those more familiar with them. It is, therefore, easier to share representations.

Behaviours and interactions between players

Situation simulation exercises for people taking part in a role-playing game session influence the way in which they make their decisions and interact with the other participants. Recording arguments put forward during discussion phases between players is a way of gleaning information on the rationalities mobilized for these decisions. Duplication of roles verbalizes the reasoning, which makes it more easily accessible, but hedges the exploration of more standard behaviours as shown in situations of experimental economics (Bornstein and Yaniv, 1998). Lastly, observing player attitudes and behaviours is another source of information. This activity has to mobilize assistants capable of performing this function (see Chapter 2) and totally devoted to the task (one assistant stationed in each strategic place). The resulting observations can often prove very rewarding. They are analysed collectively during the debriefing phase of a role-playing game session. They can also be used to activate the changes in the model used by questioning the domain model, the conceptual model or the simulation model. It is the first driving force in the iterative process.

Analysis

After exploring the various simulation scenarios, the participants make inferences from what they have observed and what they felt was revealing. It is fundamental to allow sufficient time for collective discussion of the conclusions that each individual has drawn from the experiment, so that these conclusions can be shared and potentially invalidated given the distance between the virtual world used to reach them and the actual world that could be subjected to them. This collective discussion of conclusions is even more important when they involve individual participants personally. Participants must be given a chance to re-establish their identity to avoid losing face before their group (Richard-Ferroudji, 2008). This is achieved through the collective debriefing presented in Chapter 1.

In role-playing game workshops, this analysis is hugely beneficial in making available observations on the progress of the session. Thus, if the decisions of players are recorded on a computerized medium, decisions judged problematical can be explained through speeded-up sequence replays or the various changes shown by replaying other sessions organized elsewhere. If an observer has followed the negotiation phases, the presentation can be analysed and the arguments discussed. If the session has been filmed, the attitudes can be analysed or an attempt can be made to interpret players' movements in the game space (who has been taking the initiative to trigger interactions with the others, and so on).

The analysis phase is when the return of the virtual world to the real world is addressed. The participants are invited to say if they have spotted the links between what the simulation experiment has exhibited and what goes on in reality, or whether, on the contrary, certain aspects exhibited during the simulation experience are never seen in reality. This is the second and main driving force in the iterative process: the participants can raise doubts over the representations mobilized, their implementation or develop the questions asked during this analysis. Finally, over and beyond identifying similarities, the analysis must include a form of workshop assessment by the participants, especially asking them whether they perceive any type of advantage in participating compared with the question asked (see Chapter 6).

Singularity, complementarities and versatility in modelling tools

This chapter has presented the various stages and methods in constructing virtual worlds for the purpose of shared representation and collective exploration of possible futures. The stages have been presented in a certain order, which makes you think that the sequence always advances in this order, with the end of one stage heralding the start of the next. This is not true in practice: there are frequent interferences between the various stages. This feature is reinforced again when the stakeholders are involved, to varying degrees, in a certain number of stages and when they are also given the chance to steer the process. The companion modelling approach has a duty to be adaptive and its tools must be flexible. Through the diversity of experiments analysed, we discuss the duality between the degree of singularity and the degree of genericity of the models, which can be related to their degree of abstraction/realism. Then we review the diversity of modes when combining the two main types of simulation tools used in companion modelling, namely computerized simulation models and role-playing games.

Singularity/genericity of modelling tools

During each ComMod process, a singular model, specifically developed to represent the reference system under study, is co-designed. Conversely, a generic model, undoubtedly useful as potentially suitable in different contexts, is not co-designed (or co-designed just once). Being a methodology that highlights the co-design process, what are the implications for companion modelling regarding the status of generic models? Sometimes we use the term ‘disposable models’ to state that a model is just a snapshot of representations and questions at a given stage. Using it makes the questions evolve and designing it makes the representations change, therefore, it is only relevant in catalyzing the process at a given time. To overcome this narrowness, making, from a peculiar case, a model more generic would allow widening its representativeness. Linking such a model to a given reference system is a way to disclose its type. Serving as a reference, a generic model can also keep track of the diverse adaptations (disposable models) that were specialized to make it more relevant to specific contexts.

The singularity/genericity of a model is often directly related to the degree of realism of the representation of the reference system, which is linked to the degree of complexity of the model. Three levels can be distinguished.

When there is an explicit linkage to a specific reference system, the actors, the resources and the spatial configuration are straightforwardly specified in the model from the corresponding characteristics of the reference system. This is often the option preferred at first by the local partners. To recognize in the model some particular features of the system under study make the participants confident about the ability of the tool to represent real-life issues. It may happen that this quest for realism is mainly justified by the need for participating stakeholders to become confident in the model under development. Thus, in the Domino Réunion case study, a detailed demographic module that was first included in the computerized simulation model was not discussed later on in the prospective scenarios. Generally, modellers seek more realism. This bias restricts the ability of the model to distance its users from their reality, which can prevent the consideration of some scenarios that would let sensible real-life aspects surface again.

When there is an implicit linkage to a specific reference system, the model is an archetype based on a realistic simplification of the actors, the resources and the spatial configuration of the real system. For the participants to legitimate the simplifications, some key features, independent from any peculiar details, have to appear in the model. For instance the SylvoPast (Nîmes-Métropole) case study (Étienne, 2003) provided a representation of a typical Mediterranean forest based on mean proportions of the vegetation layers observed in that region.

Finally, when there is no linkage to any particular reference system, the model provides an abstract representation that simply aims to deal with an issue. The users may repel a tool too abstract as being insignificant for them, hindering their ability to consider simulation outputs as plausible anticipated situations. However, it may also happen that the participants themselves reckon that a simple and abstract tool best suits their needs to share representations. Thus, during a project entitled 'Levelling the Playing Field' carried out in the Philippines, the abstract version of the CherIng role-playing game, usually used as a pedagogical tool in training sessions about the companion modelling approach, was finally more appreciated by the participants than a contextualized version.

Combinations of various simulation models in implementing the approach

In the majority of ComMod case studies, several simulation models are combined. Following a first typology of benefits related to the combined use of role-playing games and computerized simulation to address negotiation issues (Barreteau, 2003), we review here the advantages of each type of combination in supporting modelling activities, such as design, communication, exploration or validation.

Filiation links between models exist in all the ComMod case studies combining several simulation models. Thus even in the most prolific case study (seven simulation models developed in six years), Mae Salaep, common elements are found between the various models developed to address the problem of erosion, access to credit and sharing of water.

When the role-playing game precedes the computerized simulation, it supports the communication of the conceptual model, whereas the computerized simulation enforces and extends the prospective dimension by allowing the exploration of more scenarios than the role-playing game. In such a configuration, two scenarios stand out.

In the first one, the computerized simulation model is a direct transcription of the role-playing game and is the most often used in the continuity of (or only a few days after) the role-playing game session, with the same participants. The SelfCormas application in Senegal opened the way to this type of combination (d'Aquino *et al.*, 2003). The understanding of the direct link uniting the two tools is made easier by the proximity of the interface between the users and the model, particularly the spatial representation: what appears on the computer monitor is a faithful reproduction of the game board. Drawings on cards used in the game can also be digitized and displayed. This is the ideal combination for participants to understand clearly the structure and principles of the conceptual model when playing it, and to propose and subsequently monitor scenarios on the computer fully aware of the status of the computerized simulation model. This does not appear as a complex tool issuing recommendations but a more efficient role-playing game equivalent for exploring the scenarios.

The second use scenario for a computerized simulation model following on from a role-playing game, less frequent than the first, refers to a virtual agent model that is not reproducing a role-playing game, but often a more developed representation of the reference domain. Role-playing game sessions are then supporting the process of designing the computerized simulation model. An application in Thailand (Lam DomeYai) demonstrated that this association method can prove more effective in developing relatively complex computerized simulation models with local stakeholders who can then take it over: at the end of this project, the villagers who had taken part in the virtual agent model development process (which was based on three role-playing game sessions) went to present 'their' simulation tool to a seminar at the university. In this scenario, unlike the first, the designer of the virtual agent model capitalized on the analysis of several role-playing game sessions so that he could base defining the virtual agents on typical rather than special behaviours.

When the computerized simulation model precedes the role-playing game, the role-playing game is frequently a simplification of the virtual agent model, which participants not very familiar with this type of computerized simulation model can find useful in understanding its structure ('open the black box'). For instance, Njoobaari (a role-playing game) and SHADOC (a computerized simulation model) are two related simulation tools representing the operation of irrigated systems in the Senegal river valley (Barreteau *et al.*, 2001). This type of combination also relates to situations in which the role-playing game includes certain modules created during the development of the virtual agent model, mainly those linked to natural processes, like the pine dissemination module in the Méjan case study (Étienne *et al.*, 2003).

The recent trend towards hybrid simulation models, which by their very structure incorporate the specific properties of role-playing games and computerized simulation models, demonstrate that both types of tool are very useful in companion modelling implementation. The hybrid simulation models offer interesting possibilities in managing the time constraint of role-playing games most effectively. The avatars thus take over from players certain repetitive actions (MéjanJeu) or with shorter time periods than those taken in the role-playing game framework to make key decisions (Pieplue). Adding virtual agents to a reasonable number of human agents is also achievable with a hybrid agent model (AtollGame), giving the simulation model enough agents to cope with the question asked.