Supporting Social Communication Skills in Multi-Actor Artificial Realities

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ABSTRACT

Our aim is to support groups of people in using their natural social communication skills in distributed virtual environments. This is achieved through the introduction of a spatial model of awareness which defines the key concepts of *aura, awareness, focus, nimbus, adapters and boundaries*. First, we briefly review some of the social science background which has informed the development of this model. Next we define the model itself. Following this, we show how a few key simplifications results in the notion of different awareness states between participants. Finally, we discuss how this simplified version of the spatial model can be used as a guide to the implementation of collaborative virtual reality systems as an *application of existing VR systems*, including an example from the DIVE system.*

KEYWORDS: Awareness, Cooperative Work, CSCW, Spatial Model.

1. INTRODUCTION

This paper introduces a spatial model of interaction which aims to support groups of people in using their natural social communication skills in distributed virtual environments. In so doing, it examines the relationship between the two fields of Virtual Reality and Computer Supported Cooperative Work (CSCW). At the core of the paper is the contention that the provision of virtual

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spaces as environments for cooperative work enables people to employ a rich set of social spatial skills for managing interaction and the sharing and exchange of information.

The goal of our paper is to describe a realisation of a spatial model of cooperative work which supports these skills in virtual computer space. The core concepts which constitute this model, namely aura, focus, nimbus, awareness, adapters and boundaries, have already been presented elsewhere [4]. The primary aim of this paper is therefore to describe a technique for realising this model based on the notion of different *awareness states* that emerge when a few simplifying assumptions are made. In particular, we discuss how the model might be realised as an application of existing VR environments.

Many researchers have previously described systems to support cooperative work based on spatial metaphors. These include shared virtual reality [5,21,12,20], audio/visual meeting rooms [6], media spaces [9,18] and also multi-user recreational environments [2,17]. And, of course, the use of space based metaphors is highly familiar from the design of interfaces to personal workstations (e.g. the 'desktop' metaphor). A secondary aim of this paper is to extend this body of work towards more flexible support for social interaction.

Section two presents the social science background which has informed the development of our model (we believe this relationship to social-science theories and observational studies to be a key aspect of the model). Section three then summarises the model's main concepts. Section four shows how the introduction of a few key simplifying assumptions results in the notion of awareness states. Finally section five describes how the spatial model and the notion of awareness states can be used to inform a virtual reality implementation of the model.

2. SOCIAL BACKGROUND

This section summarises key observations from the social-sciences that have shaped our model. Much previous work in the design of single user interfaces has exploited individual's cognitive spatial skills (e.g. the ability to spatially classify and navigate). However, we argue that space has a social significance too and that how spatial considerations relate to social interaction is just as relevant for the design of collaborative systems. The following paragraphs consider the social significance of segmenting and bounding space; the nature of activity participation and awareness in space; and the use of space in negotiating access to people (conversation management) and other shared resources.

2.1. The Social Significance of Space as a Practical Resource

In an influential treatment, which we follow in several respects, Giddens (e.g. [10]) has discussed some of the many ways in which space and time can be regarded as *resources* for activity and interaction. He introduces the notion of 'modes of regionalisation' to try to capture the interdependence of geographical space and social practices. Space undergoes different modes of regionalisation, through which distinctions between different spaces (or 'locales' in Giddens' term) are produced. He also notes the different *uses* to which different spaces are put. Furthermore, these uses relate to the different social practices that are carried out *in* those spaces and *for which* those spaces serve as a resource: for example, tools related to cooking are kept in the kitchen, 'tools' related to cleansing the body are kept in the bathroom. The general point is that the existence of a space constitutes a key resource for establishing and enabling an activity. The same is also true for spaces which are used for transit between other spaces — corridors, foyers, squares and other spaces regarded as 'public'.

To identify the form of a region, *boundaries* are constructed ([10] p.121). These boundaries may be symbolic or physical. Walls between rooms, screens, customs and immigration checkpoints or marks on a map are all familiar examples of the physical-symbolic means for marking a boundary and hence constructing a region. International borders mark the territory of nations. State and regional borders mark administrative and legal territories. The elementary operation of drawing up a boundary is of utmost significance. Not only do boundaries differentiate spaces, they can serve to include some elements (people, resources, objects and so forth) while excluding others.

The relation of bodies in space to boundaries within space often produces 'front' and 'back' regions. For example, at the boundary between an organisation's building and the outside world, there may be a reception area. For many organisations, presenting a well decorated, comfortable and elegant reception area is of great importance. It is, after all, the 'front' of the organisation that the visitor first sees. The human body itself, of course, has clear front and back regions and these too are of interactional significance. The maintenance and manipulation of front (or 'face') versus back distinctions in social interaction has been emphasised on numerous occasions in the work of Goffman [11].

2.2 Activity in Space: Participation and Awareness

In all the examples given so far, marking out a space with boundaries and constructing regions which can serve as resources is important to social practice and ordering what people can and cannot do. Let us now offer the following conjecture: *boundaries in space afford different modes of participation in a social practice alongside different modes of awareness.* For example, the boundaries which separate the inside of an office from the outside enable the differentiation between who can participate as an office member and who can participate as a visitor, supervisor or whatever. In addition, boundaries afford differences between modes of awareness. 'Open plan' offices often employ certain forms of boundary to define separate office regions but do so in a way which enables different forms of awareness to come into existence from those possible in traditional, walled office spaces. The 'semi-permeability' of low, mobile room dividers affords a different profile of awareness of one's neighbours and their activities than does the relative impermeability of a wall. This theme of boundaries in space will be returned to in section 3.4.

Awareness Through Seeing 'Out of the Corner of One's Eye'

The inter-relations between space, awareness and participation are ubiquitous in working practices. Let us illustrate this with some examples taken from recent CSCW literature.

Heath and Luff have extensively studied the activity of control room operators in the London Underground, documenting in some detail how the two operators co-ordinate their activities while maintaining their different responsibilities [13]. This is achieved by overhearing, 'seeing out of the corner of one's eye' and other forms of monitoring of the other's conduct which establish co-ordination without interruption. In addition, the operators conduct their activity in such a way as to make it available to each other as potentially overhearable or monitorable. Heath and Luff have some examples of how an operator can engage in quite exaggerated body movements, gestures and ways of talking to bring his conduct to the attention of his colleague. However, in all this, it is important to note that the spatial arrangements of the control room are such that these monitorings and displays are possible. By providing the controllers with adjacent yet separate desks, they can maintain an awareness of each other's individual work without intruding upon it.

Awareness Through Seeing 'at a Glance'

The working environment of the London Underground control room operators includes a number of different artefacts — notebooks, schedules, timetables, computer screens, headsets, microphones. In addition, along the length of one of the walls of the control room is a representation of the underground line — called 'the fixed line diagram' — using a strip of lights. The location of trains is shown by illuminating the lights corresponding to the section of track where the train is. In this way, the goal of a regular, uninterrupted service can be 'seen at a glance' as a series of equally spaced illuminations. However, that it is publicly available and spatially located as it is matters greatly to the working activity of the controllers. Both can see it and both can see that the other can see it.

Arranging space so as to afford awareness through 'seeing at a glance' is a prominent feature of many working activities. In studies of Air Traffic Control, Hughes, Randall and Shapiro how 'flight strips' spatially arrange information about air traffic, how these strips themselves can be arranged in a rack to signal problematic flights, how flight control suites themselves lay out the strips and other resources so that the practised on-looker can see how smoothly or otherwise the work is going [16]. Similar points about the inter-relations of spatial arrangements, visibility, awareness and intelligibility have been made by Anderson and Sharrock in a study of the processing of invoices in an entrepreneurial firm [1].

While these are just two sets of examples from emerging research in CSCW, they hint at a general point. Space and spatial arrangements of bodies, devices and various forms of representation (charts, diagrams and so forth) are important for sustaining various forms of interaction, participation and awareness.

2.3. Negotiation across space

The implicit awareness of the presence and activity of others afforded by space enables a range of subtle negotiations among its inhabitants. Continual awareness of others allows people to flexibly modify their own activity in social situations. It also provides a degree of predictability concerning the likely actions of others (you can easily see when someone is heading across the room to talk to you or when they are heading for the door). Key features of this negotiation are the high degree of autonomy enjoyed by participants, the extremely rapid feedback provided and the fact that social mechanisms of control gradually emerge, evolve, adapt and can be broken when desired. We now consider two specific cases in more detail: negotiating "access" to other people and negotiating access to non-human resources.

Negotiating access to people - conversation management

Conversation management is a prime example of negotiating access to people. This is a subtle art which covers joining and leaving conversations and negotiating turn-taking and repairs [19]. Space assists in joining conversations by signalling the gradual approach of other people. This allows both the approaching and the approached groups to adjust their behaviour to accommodate the others (e.g. changing tack away from a sensitive subject and making space for the new participants). Space also allows us to signal that we don't wish to be interrupted either crudely through devices such as closed doors or more subtly through body posture and positioning. We also use space to signal that we wish to interrupt someone or re-orient their attention (e.g. hovering near their shoulder or waving). During conversation, we use properties of space to show who is speaking and who wishes to speak next. In particular, orientation and gaze direction are used as flexible interaction mechanisms. Finally, when we are talking, we can judge the reactions of others from their use of space (e.g. restless shifting around can signify boredom and suggests that we should give way to someone else). These are just a few examples of the importance of space and spatialised phenomena to the management of conversation.

Negotiating access to other resources

Space also supports us in negotiating access to shared resources by providing awareness of who is using them and who intends to use them. Consider a whiteboard. As a communication tool it has no built in control mechanism to stop conflicting use (e.g. two people drawing over the top of each other's work). However, its placement in a space means that we are instantly aware of who is using it and also who is approaching it. This enables us to develop social conventions for controlling access to the resource. There are many examples of such mechanisms. resulting in behaviours such as queuing, jostling and scrumming.

All of these observations when take together provide a compelling motivation for adopting a spatial approach to CSCW. The goal of our model is to provide a powerful set of mechanisms which afford the same kind of flexibility in the use of spatial resources as we have documented so far. The following sections now turn their attention to consider a spatial model of interaction which aims to support the spatial skills and phenomena described above.

3. THE SPATIAL MODEL OF INTERACTION

We now define the key concepts which constitute our spatial model of interaction (the model has been defined in detail in a previous paper [4] - this section summarises it here for completeness).

The goal of the spatial model is to provide a small but powerful set of mechanisms for supporting the negotiation of social interaction across a range of virtual spaces. More specifically, we intend the model to provide an alternative to other forms of turn-taking and control in CSCW systems such as 'floor control' in conferencing systems. A further goal of the model is to support the development of large-scale shared virtual spaces (i.e. spaces that contain many inhabitants).

The spatial model, as its name suggests, uses the properties of space as the basis for mediating interaction. Thus, objects can navigate space in order to form dynamic sub-groups and manage conversations within these sub-groups. Next, we introduce the key abstractions of *space, objects, media, aura, awareness, focus, nimbus, adapters* and *boundaries* which define our model.

3.1. Space and objects

The most fundamental concept in our model is *space* itself. Michael Benedikt defines space as "freedom to move" and proceeds to discuss the structure of virtual space in terms of combinations of dimensions which might behave in continuous or discrete ways [3]. Following this, we also allow virtual spaces to have any number of dimensions where each dimension allows some measure of position. Put another way, space is defined by 'spatial metrics' - well defined ways of measuring position and direction across a set of dimensions. This general definition of space is intended to allow a wide range of potential applications of the model.

Space is inhabited by *objects* which might represent people, information or other computer artefacts. Any interaction between objects occurs through some *medium.* A medium might represent a typical communication medium (e.g. audio, vision or text) or perhaps some other kind of object specific interface. Each object might be capable of interacting through a combination of media/interfaces and objects may negotiate compatible media whenever they meet in space.

3.2. Aura

The first problem in any large-scale environment is determining which objects are capable of interacting with which others at a given time. *Aura* is defined to be a sub-space which effectively bounds the presence of an object within a given medium and which acts as an enabler of potential interaction [7]. Objects carry their auras with them when they move through space and when two auras collide, interaction between the objects in the medium becomes a possibility. It is the surrounding environment that monitors for aura collisions between objects. When such collisions occur, the environment takes the necessary steps to put the objects in contact with one another (e.g. exchange of object IDs, addresses, references or establishment of associations or connections). Thus, aura acts as a fundamental technological enabler of interaction and is the most elementary way of identifying a subspace associated with an object. An aura can have any shape and size and need not be around the object whose aura it is. Nor need it be contiguous in space. Also, each object will typically possess different auras for different media (e.g. with different sizes and shapes). Thus, as I approach you across a space, you may be able to see me before you can hear me because my visual aura is larger than my audio aura.

3.3. Focus, Nimbus and Awareness

Once aura has been used to determine the potential for object interactions, the objects themselves are subsequently responsible for controlling these interactions. This is achieved on the basis of quantifiable *levels* of awareness between them. The measure of awareness between two objects need not be mutually symmetrical. A's awareness of B need not equal B's awareness of A. As with aura, awareness levels are medium specific. Awareness between objects in a given medium is manipulated via *focus* and *nimbus*, further subspaces within which an object chooses to direct either its presence or its attention. More specifically, if you are an object in space:

- The more an object is within your focus, the more aware you are of it.
- The more an object is within your nimbus, the more aware it is of you.

The notion of spatial focus as a way of directing attention and hence filtering information is intuitively familiar from our everyday experience (e.g. the concept of a visual focus) and parallels have been explored in previous work on user interface design (e.g. fisheye views [8]). The notion of nimbus requires a little more explanation. In general terms, a nimbus is a sub-space in which an object makes some aspect of itself available to others. This could be its presence, identity, activity or some combination of these. Nimbus allows objects to try to influence others (i.e. to project themselves or their activity to try to be heard or seen). The necessity for a concept of nimbus to complement that of focus becomes clear once we remember the notable phenonenom uncovered in Heath and Luff's work where London Underground control room operators often projected their activity so as to encourage awareness among others (see section 2). Thus, nimbus is the necessary converse of focus required to achieve a power balance in interaction.

Objects negotiate levels of awareness by using their foci and nimbi in order to try to make others more aware of them or to make themselves more aware of others. We deliberately use the word negotiate to convey an image of objects positioning themselves in space in much the same way as people mingle in a room or jostle to get access to some physical resource (see section 2). Awareness levels are calculated from a combination of nimbus and focus. More specifically, given that interaction has first been enabled through aura collision:

> *The level of awareness that object A has of object B in medium M is some function of A's focus in M and B's nimbus in M.*

For the purpose of characterising a general model, we should not constrain what the relation might be nor actually how awareness computations take place. A's awareness might be, for some metrics, an arithmetic sum of A's focus on B and B's nimbus on A, but there are clearly many other plausible possibilities. In any implementation of the spatial model, appropriate metrics and relations between focus and nimbus computations have to be defined to, in turn, compute awareness. However, for present purposes, the important point is that the resulting quantified awareness levels between two objects can used as the basis for managing their interaction. Exactly how this is achieved is again a matter of interpretation by a particular application. One approach might be to use awareness levels to directly control the medium (e.g. controlling the volume of an audio channel between two objects). Another might be allowing objects to actively react to each others presence depending on specified awareness thresholds (e.g. I might automatically receive text messages from you once a certain threshold had been passed).

3.4. Adapters and Boundaries

Next we consider how aura, focus and nimbus, and hence awareness, are manipulated by objects in order to manage interactions. We envisage four primary means of manipulation:

1) Aura, focus and nimbus may most often be *implicitly* manipulated through fundamental spatial actions such as movement and orientation. Thus, as I move or turn, my aura, focus and nimbus might automatically follow me.

2) They may on occasion be *explicitly* manipulated through a few key parameters. For example, I might deliberately focus in or out (i.e. change focal length) by simply moving a mouse or joystick. Below, we also discuss the possibility that awareness states might be named and that these names could be used to manipulate focus/nimbus.

3) They may be manipulated through various *adapter objects* which modify them in some way and which might be represented in terms of natural metaphors such as picking up a tool. Adapters support interaction styles beyond basic mingling. In essence, an adapter is an object which, when picked up, amplifies or attenuates aura, focus or nimbus. For example, a user might conceive of picking up a 'microphone'. In terms of the spatial model, a microphone adapter object would then amplify their audio aura and nimbus As a second example, the user might sit at a virtual 'table'. Behind the scenes, an adapter object would fold their aura, foci and nimbi for several media into a common space with other people already seated at the table, thus allowing a semi-private discussion within a shared space. In effect, the introduction of adapter objects provides for a more extensible model.

4) Finally, aura, focus and nimbus may be manipulated through *boundaries* in space. Boundaries divide space into different areas and regions and provide mechanisms for marking territory, controlling movement and for influencing the interactional properties of space. More specifically, boundaries can be thought of as having four kinds of effects: effects on aura, effects on focus, effects on nimbus and effects on traversal (i.e. movement). Furthermore, these effects can be of four sorts: obstructive, non-obstructive, conditionally obstructive and transforming [15]. These effects are also defined on a per medium basis and different boundaries may mix these effects in different ways. For example, a 'virtual door' might conditionally obstruct traversal, aura, focus and nimbus (the condition being the possession of a key) whereas a 'virtual window' might obstruct traversal but not obstruct aura focus and nimbus. Of course, there may also be types of

boundary which do not have any real-world counterpart like one way mirrors you can walk through.

It is worth exploring the notion of boundaries and adapters a little further. Any object can act as a boundary and, although one tends to think of boundaries in terms of walls, doors and windows, we are all familiar with the fact that furniture and even people can make very effective boundaries (e.g. a well placed desk or a row of policemen). Thus, although it may help to explain the model if we conceive of boundaries and adapters as being different kinds of object, they are really the same thing. In fact, at the most abstract level, all objects can serve to obstruct, non-obstruct, conditionally obstruct or transform aura, nimbus and focus. In other words, we are really identifying fundamental properties of all objects in space.

4. MODES OF AWARENESS - A SIMPLE DISCRETE INSTANTIATION OF THE MODEL

The previous section has defined the spatial model in a deliberately general way so that there may be many kinds of space, and so that aura, focus and nimbus may have arbitrary shapes, values and properties. We now show how a few assumptions result in a simpler "discrete" (but still useful) version of the model based on the notion of awareness states. There are two reasons for doing this:

1. To support further analysis of the model in relation to previous observations on the importance of awareness in cooperative work.
2. The simplified model can be used as the basis for lightweight implementations, realised as *applications* of existing VR platforms (i.e. without the need for a specialised distributed architecture).

The following discussion centres around the relationship between focus, nimbus and awareness. More specifically, the following simplifying assumptions are made:

- Aura collision has already occurred.
- Focus and nimbus are both binary valued functions such that an object is either completely in or out of focus/nimbus (giving values of 1 and 0 correspondingly). Furthermore, the regions of space in which focus an nimbus take the value 1 are continuous and well bounded. In other words, focus and nimbus are simple containment spaces such that an object is either in or out of another's focus and/or nimbus.

We also introduce the following notation to represent the state of focus and nimbus at a given moment in time (there are several possible notations - this one has the advantage of being easy to understand although it does tend to imply specific shapes of foci and nimbi that may not actually be the case).

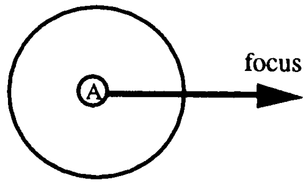


Figure 1: A graphical notation for focus and nimbus

Now, considering all the possible arrangements of focus and nimbus for two entities, it is possible to define ten different modes of mutual awareness as follows. An entity may direct its focus on the other or not. Similarly, it can project its nimbus on the other or not. This gives four possible ways in which one entity can arrange its nimbus and focus relative to another. As we are dealing with a two entity case, we have $4^2=16$ possible arrangements of mutual foci and nimbi. However, six of these can be eliminated by symmetry, leaving ten. These are depicted in figure 2, together with a tentative name for the resulting awareness state in each case.

This instantiation of the spatial model is of interest because it captures, albeit crudely, some aspects of previous empirical studies of work practice (see section 2). For example, case 3, which we have named *mutual overhearing* captures some aspects of the ways in which London Underground control room operators make their activity available *to each other*. Similarly, case 7 involves both parties projecting their activity over each other but here one party is focusing on the other and attending to that party's activity. Again, this might capture some aspects of the mode of mutual awareness when one operator comes to attend to the activities of another.

Symmetry, Congruence and Reciprocity

This analysis also suggests certain properties which occur in a number of the cases concerning relations between the foci/nimbi of the two entities. Let us define symmetry as follows: a mode of mutual awareness exhibits symmetry if either (i) A is focusing on B and B is focusing on A or (ii) A is projecting its nimbus on B and B is projecting its nimbus on A. A mode of mutual awareness may be symmetrical in up to two ways - with respect to focus or with respect to nimbus.

Now let us define congruence as follows: a mode of mutual awareness is congruent if A is focusing on B and B is projecting its nimbus on A. A mode of awareness is reciprocal if it is both symmetrical and congruent. It is fully reciprocal if it is congruent and symmetrical with respect to both nimbus and focus.

To what use can such an analysis be put? First, it is important that such representations be handled with care - remember they are gross simplifications of the concept of awareness, if only because of the simplifications involved in this (discrete) instantiation of the spatial model. However, perhaps we can point to some possibilities.

First, these named modes and transitions between them might simplify nimbus/focus manipulations for inhabitants of a virtual space. Rather than saying "project nimbus in such a way" and "direct focus in such a way", they can say "ignore" or "monitor" or "make congruent" or "make symmetrical" etc. In fact, as we shall indicate in the implementation described in the next section, a surprising degree of expressive power can be achieved by distinguishing only four different awareness states and governing one's interactions with another object in their terms.

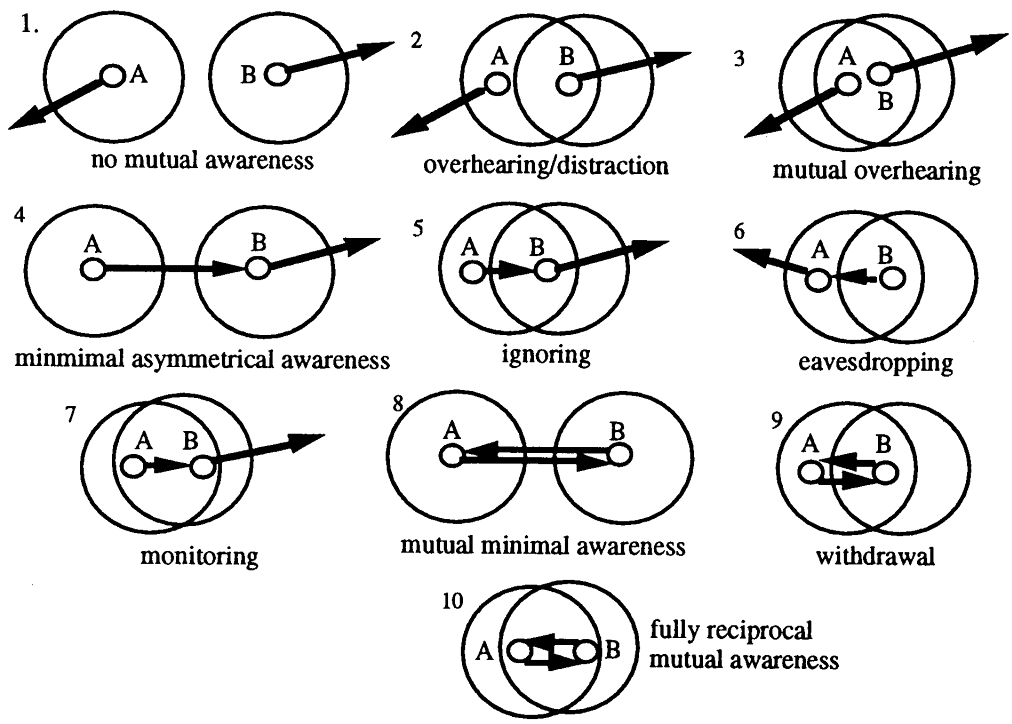


Figure 2: Derivation of 10 awareness states

In addition to these uses of the analysis of modes of awareness which will be discussed in greater depth shortly, we are also exploring some further possibilities. For example, awareness mode names and the relations between them can serve as state names in state machines for governing the behaviour of reactive objects in a virtual space. That is, one can consider objects which engage in processing of some sort in response to your awareness of them and their awareness of you. Finally, one can imagine rooms (or other bounded spaces) in which only a certain subset of these modes of awareness are possible together with the transitions between them. Thus, a virtual control room may be an environment in which the modes noted above (modes 3, 7 and 10) and the transitions between them are the most readily possible. This would be one way of integrating a room metaphor with an interactional approach to virtual spaces.

In summary, we have shown how a few simplifying assumptions about the nature of focus and nimbus result in the notion of different awareness states between entities. The following section describes how these may then guide a simple demonstration of an implementation of the model.

5. IMPLEMENTING THE MODEL AS A VR APPLICATION

There are several approaches to implementing the spatial model. One is to construct a new VR system in which aura, focus and nimbus are handled by dedicated services within the distributed architecture (an example of such a system is MASSIVE which relies on specifically tailored aura collision managers and specific spatial model peer protocols [23]). Although this approach may offer the most general and scaleable realisation of the model, it has the disadvantage of requiring significant alterations to whatever VR platform is chosen as its basis. This section therefore describes how the simplified discrete version of the model outlined above may be used as the basis for a lightweight implementation at the VR application level. Although less general, this means that the model may be relatively easily introduced on top of existing VR platforms. In our case, the existing platform is DIVE.

5.1. Overview of DIVE

DIVE [21] (Distributed Interactive Virtual Environment) is a distributed multi-user virtual reality system, suited for building and running applications in a high performance computer network setting[1]. The system consists of a set of communicating (UNIX) processes, running on nodes (computers) distributed within a local or wide-area network. Figure 3 shows a network of 3 coexisting DIVE world contexts, made up out of 8 processes running on 3 different computers (nodes), one of which is equipped with 3D glasses and a wand. The two local area networks are connected via a high speed backbone network. DIVE processes have access to a number of databases, each one describing a virtual context (or world). For each world, there exists an associated process group, consisting of all the processes that are currently members of that world. When a process joins a specific process group, it receives a complete copy of the actual world data. The different copies of the world database are then kept consistent by the use of reliable multi-cast protocols so that the databases can be updated concurrently. A process can only be a

[1]Implementations of DIVE exist for several types of UNIX platform. For information about the availability of DIVE please send EMAIL to dive–request@sics.se.

member of one "world" process group at a given time but it is easy and quick to go *between* different worlds.

DIVE supports several simultaneous users where each user can have a different hardware configuration. Each user controls his or her viewpoint individually and can navigate freely through the environment. Unique self-representations (embodiments) are used to allow participants to be aware of each other's presence and actions. The representations may range from simple block-like figures up to complex models of, for example, human bodies. Figure 4 shows a DIVE conference. In the scene a conference table and a multi-user white board can be found. Both of these collaborative tools use the mechanisms of the spatial model to handle interaction and control. There is also a number of users represented. To the left and right, humanoid user embodiments are shown. In the middle there is a "classic" DIVE simple "blockie" representation. Finally there is also support for conference participation via conventional video-conference technology as shown by the presence of the "virtual" video monitor on top of the conference table.

Objects and applications in the DIVE environment can use signals to control their behaviour by specifying a number of actions to be performed when certain events occur. An object's behaviour is defined as a simple finite-state machine, consisting of a set of states and directed arcs. Each arc specifies for what signal, or event, transition is allowed, and what operations to perform when this happens. The types of operations include translations, rotations, generation of sound and changes of object properties, such as colour and spin etc. The state machine is described in a DIVE data file that is read by the system when the object is to be introduced into the system. Once the object exists, its behaviour can be changed and manipulated dynamically like any other object property.

5.2. Implementing the Spatial Model as a DIVE application

The simplified spatial model has been integrated in the DIVE system to allow experimentation and demonstration of its applicability to various cooperative work situations. In the present implementation the aura, focus and nimbus fields are constructed as graphical objects that can be attached to representations of users and tools in the environment. The system detects aura collisions and calculates discrete awareness levels, depending on the shape, size, position and orientation of the corresponding focus and nimbus objects. The awareness state is made accessible throughout the system by the generation of an awareness signal. As long as the auras are in contact, the calculation is redone continuously, and new signals are generated if the level of awareness changes. Note that in the present implementation each awareness calculation involves two distinct objects, which means that the resulting levels are measurements of awareness between pairs of objects. By using the behaviour capability, it is possible to create autonomous objects that use awareness of events and other objects in the environment to control their own behaviour.

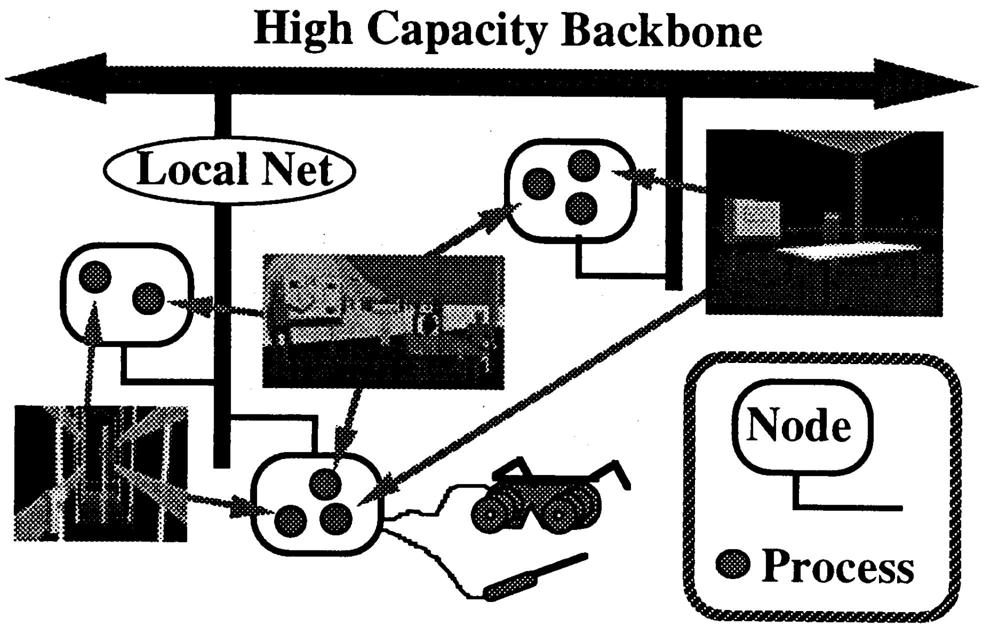


Figure 3. DIVE wide area network architecture.

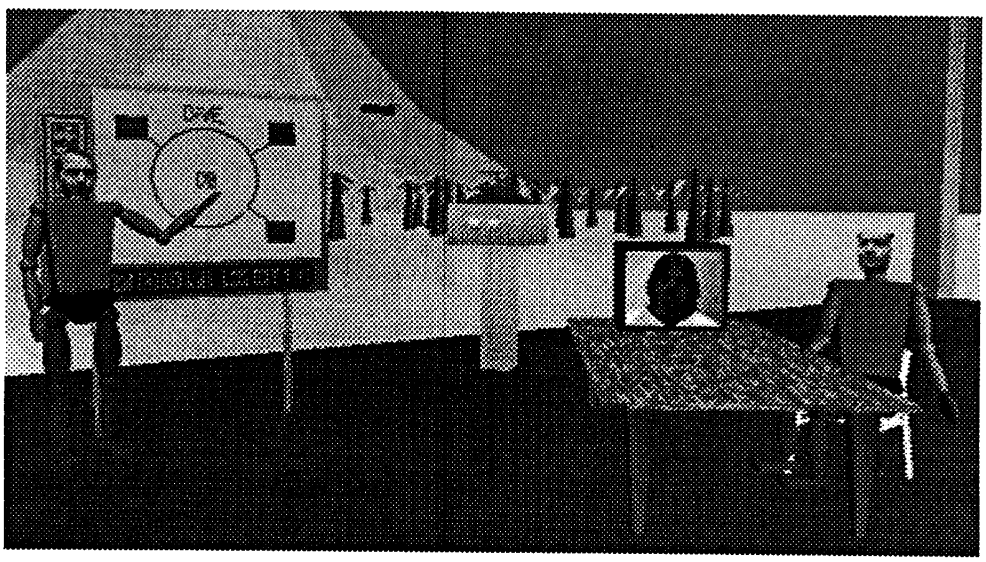
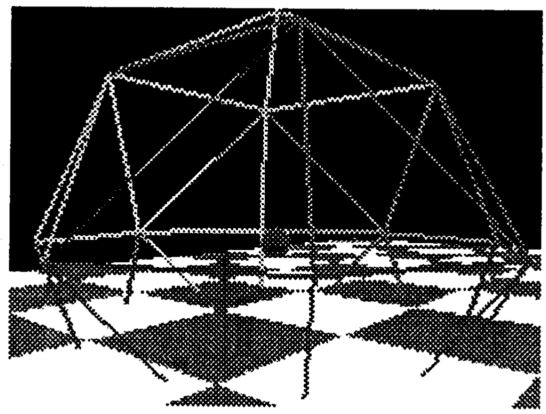


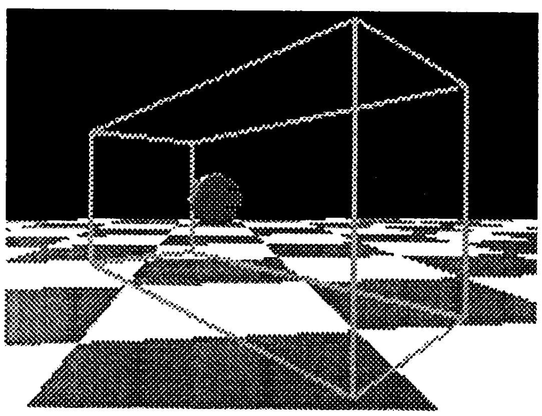
Figure 4: Cyber teleconferencing in DIVE.

5.3. Mr Nimbus - A Spatial Model demonstrator

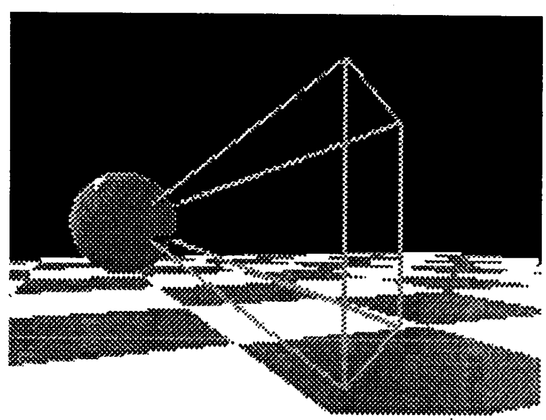
The current demonstrator allows a user to experience the effects of aura focus and nimbus through interaction with an imaginary creature called Mr. Nimbus (created by Olov Ståhl at the Swedish Institute of Computer Science). The basic features of Mr. Nimbus include a face, a pair of ears and eyes and a mouth. Both the user and Mr. Nimbus are equipped with simple graphical representations of aura, focus and nimbus and these are used to trigger and control the volume of an audio signal which is emitted by Mr. Nimbus (examples of these aura, focus and nimbus objects are also shown in figure 5). The awareness function in this demonstrator detects collisions between focus and nimbus objects, resulting in four possible awareness states (full mutual awareness, no mutual awareness and two asymmetric cases).



Example aura



Example nimbus



Example focus

Figure 5: Mr. Nimbus, equipped with aura, focus and nimbus

A further interesting feature of Mr. Nimbus is the manner in which his embodiment reflects different awareness states across both the visual and audio media. More specifically, visual cues such as flapping ears showing his audio awareness of us; high-lighted mouth showing our audio awareness of him; widening eyes showing his visual awareness of us and blushing showing our visual awareness of him are used to convey transitions between different awareness states. Figure 6 presents some examples of such embodiments.

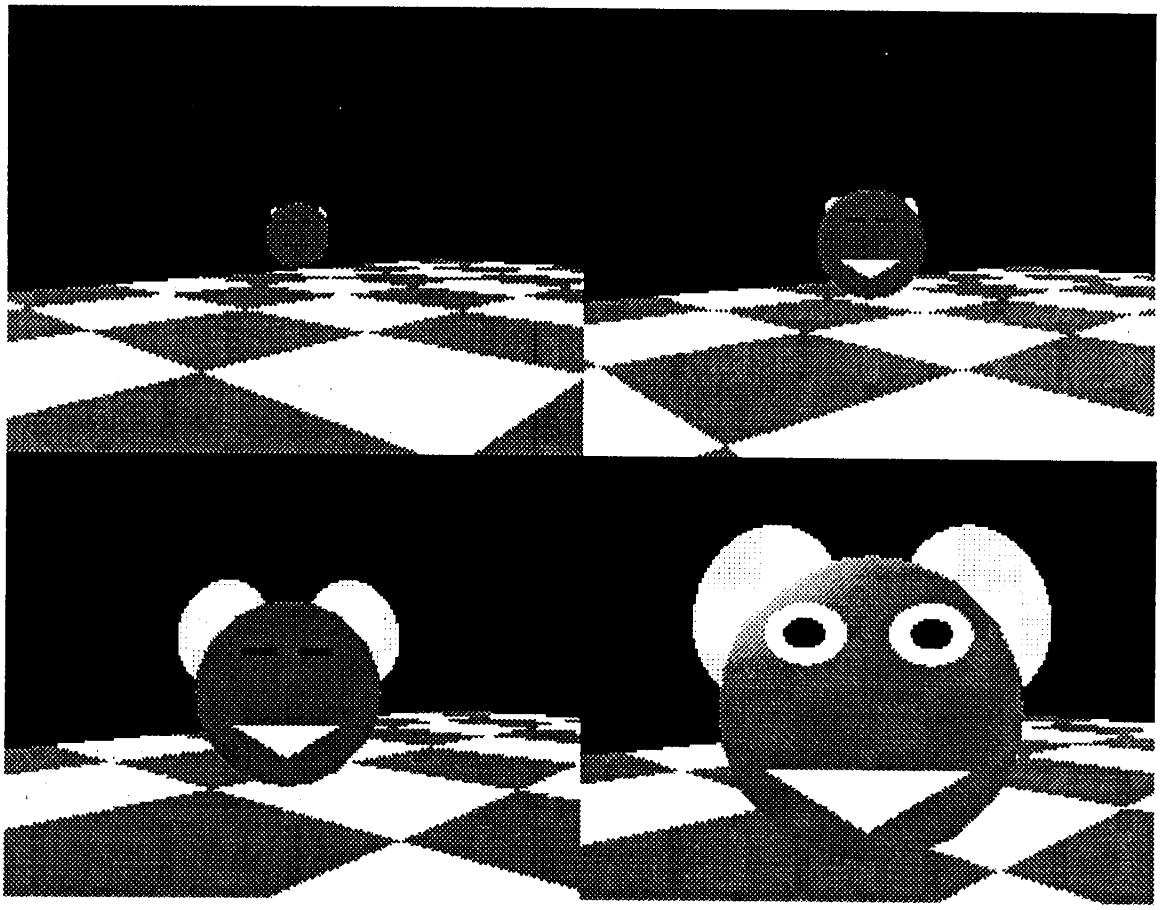


Figure 6: The embodiment of Mr. Nimbus provides awareness cues

In summary then, Mr. Nimbus shows how a simplified version of the spatial model can be realised as an application of existing VR systems by treating aura, focus and nimbus as graphical objects and then utilising the standard VR collision detection service to detect transitions between different awareness states.

6. SUMMARY

The main theme of our paper has been the realisation of a spatial model of interaction for collaborative virtual environments. In its most general form, the spatial model defines the key abstractions of aura, awareness, focus, nimbus, adapters and boundaries to support people in exploiting their natural social spatial skills in managing conversations and other kinds of interaction. The paper has explored one particular analysis of this model whereby some simplifying assumptions result in a number of discrete "awareness states" which might exist between the inhabitants of a shared space. These awareness states have then be used to inform a simple implementation of the model as an aplication of the DIVE distributed virtual environment.

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