COMPUTER-MEDIATED COMMUNICATION: A DISTRIBUTED EMPIRICAL MODELLING PERSPECTIVE

Meurig Beynon, Pi-hwa Sun

Department of Computer Science, University of Warwick
wmb@dcs.warwick.ac.uk, sun@dcs.warwick.ac.uk

ABSTRACT

This paper examines key issues relating to the potential and limitations of interactions in a virtual world. It argues that these issues are inadequately addressed by traditional approaches to communication and computation. It introduces abstract principles and software tools that offer an alternative and arguably more appropriate foundational approach. The themes of the paper are discussed in relation to diverse research programmes concerned with representing one experience by another. A historic railway accident is used as a case-study.

INTRODUCTION

The trend towards optimal world-wide telecommunications is widely perceived as bringing minds together. It is clear that, as electronic communications approach maximal speed and coverage, and the possibilities for embodiment in immersive environments are exploited, patterns of human communication are changing radically. The extent to which these developments will or can enhance human communication is more controversial. This paper is concerned with principles, techniques and tools that can be used:

- to examine the relationship between communications media technology and human communication;
- to make more effective use of telecommunications technology in sharing and distributing cognitive models.

As is common where cognitive technology is concerned, there are two perspectives to be considered. From a technological perspective, there is a natural point of arrival that is suggested by the development of a current technology. In the context of this paper, this is the point in time (to which the terms *optimal flow point* and *spatial ubiquity* refer) when it becomes feasible for groups of people at arbitrary locations on the planet to meet in virtual environments. From a human perspective, any such technological trend prompts a whole family of questions concerning the integrity of its intended goal, and the potential social impact and desirability of its expected outcome. The human perspective is important both in guarding against inappropriate use of technology, and in guiding its most effective exploitation.

The growth in world-wide communications, and of the Internet in particular, has generated new expectations for global human communication. This is reflected in the terms we adopt in discussing collaborative activity, such as *collective consciousness* and *distributed cognition* (Hutchins 1995). It has also inspired metaphors that presume the potential for unprecedented intellectual understanding and intimacy.

Understanding the significance of trends in communication raises several important issues. A profound and relevant question is*: To what extent can meeting in virtual environments resemble face-to-face encounter?* There is practical evidence to show that, when compared with face-to-face communication, computer-mediated communication often leads to an increased time to coordinate and complete tasks (Galegher & Kraut 1994). Interpreting this evidence may implicate ontological issues concerning real and virtual worlds. It is equally relevant to ask: *Do minds meet minds in face-to-face encounter?* The history of human and social conflict belies the facile assumption that communication between people is necessarily at its richest and best when they meet face-to-face in the real or a virtual world. A fundamental issue for the meeting of minds is well-expressed by William James (James 1996): "*when I seek to make a transition from an experience of my own to one of yours ... I have to get on and off again, to pass from the thing lived to another thing only conceived*".

Our excitement about future communications technology is perhaps motivated more by the conviction about its novelty than by insight into its nature. Whether or not telepresence can faithfully emulate presence, the precedents established by more mundane technologies (such as the telephone, the FAX machine and the World Wide Web) prepare us for qualitatively distinctive modes of human communication. From this perspective, the speed and ubiquity of communication is not the most significant issue: it is the fact that this communication is computer-mediated and situated in novel ways.

The perspective to be developed in this paper is based on the Empirical Modelling (EM) Project (see http://www.dcs.warwick.ac.uk/modelling/). This project has involved the development of principles, techniques and software tools for which the potential for wide-ranging application has been demonstrated.

The paper draws heavily on practical work carried out by the second author on a software tool (the EDEN interpreter) and its application to distributed EM. Extended discussion of EM techniques and tools is beyond the scope of this paper. A brief introduction is helpful in understanding the nature of the models, generated using the EDEN interpreter, depicted in Figures 1 and 2 below. The main emphasis of the paper is otherwise on the ideas that motivate the introduction and application of EM.

The EM approach is based on an agent-oriented analysis, where the focus is upon the observables that are construed to mediate agent response and action, and the dependencies to which these observables are subject in any change of state. The result of this analysis is a classification of observables with respect to the role they can play in interactions between agents. The process of agent-oriented analysis occurs in parallel with the construction of a computer-based artefact. In effect, the construction of the artefact is intimately linked with explaining the roles of observables, agents and dependencies in its referent, and interaction with the artefact accordingly retains an open-ended experimental quality.

Distributed EM exploits the client-server architecture of the EDEN interpreter. In the modelling activity, each participant makes use of a different client. The way in which modellers interact is shaped by the interactive mode of communication established by the server. This gives scope for interaction between modellers either to be determined entirely at the discretion of the server, or to be interactively programmed to reflect the explicit privileges to observe and change observables of modellers. In the versatile and flexible environment for distributed interaction established in this way, it is possible:

- to give privacy and independence to individual modellers;

- to enable people to interact with each other and with their artefact *as if* in the role of an agent within the environment being modelled;

- to support higher-level intervention, such as is needed for arbitrating where there is conflict in concurrent design (cf. Adzhiev et al 1994), and in simulating exceptional scenarios, such as a railway signal failure (Beynon 1999).

Such modelling activity is well-adapted to illustrate the principles for distributed cognition identified by Hutchins (Hutchins 1995), whereby the cognitive properties of groups are produced by interaction between structures internal to individuals and structures external to individuals.

The paper is in three main sections, respectively concerned with issues in communications technology, EM principles and their application to communication.

COMMUNICATION AND TECHNOLOGY IN CONTEXT

This section considers how technology has influenced the character of communication. It motivates the need, in understanding communication, to model interacting agents from two perspectives: *as if* in the role of an external observer, and through the eyes of the participating agents themselves. It describes how the effect of technological advance has been to promote paradigms for communication and computation that put disproportionate emphasis on the external viewpoint. This is attributed to the lack of well-accepted and effective ways of representing experiential knowledge.

BACK TO THE FUTURE

Sunday, August 25th, 1861 was a significant day in railway history. It was on that morning that two trains collided in the Clayton Tunnel, with unprecedented loss of life (see Box 1). This disastrous event was also significant in relation to the theme of cognitive technology, and of "networked minds" in particular. By a terrible irony, the accident could be attributed to the novel communication device - the telegraph - that had been introduced to prevent its occurrence. Not for the first or last time, the crash provoked questions about the benefits of technology. In the words of John Crester Craven, representing the London, Brighton and South Coast Railway (Rolt 1982): *"My board fear that the telegraphic system of working recommended by the Board of Trade will, by transferring much reponsibility from the engine drivers, augment rather than diminish the risk of accident."*

Problems of communication stemming from technological advance were central to the accident. It is hard for us to recognise the novelty of the technologies and experiences associated with the early days of railway operation, but the exercise is a useful way to put in perspective issues that are still relevant for the modern communications revolution, and arguably remain difficult to model even in our present conceptual frameworks.

Speed and locality were very significant. Driver Scott passed signalman Killick's box at such speed that Killick could not be sure whether or not he had seen his red flag. The communication between Killick and Brown at opposite ends of the tunnel was quite unprecedented in character. It linked two people who had no direct visual or aural contact, and involved virtually instantaneous events at independent locations. Hitherto the fastest mode of communication had been the train itself.

The Clayton Tunnel Disaster **August 25th 1861**

Three heavy trains leave Brighton for London Victoria on a fine Sunday morning.

They are all scheduled to pass through the Clayton Tunnel---the first railway tunnel to be protected by a telegraph protocol designed to prevent two trains being in the tunnel at once. Elsewhere, safe operation is to be guaranteed by a time interval system, whereby consecutive trains run at least 5 minutes apart. On this occasion, the time intervals between the three trains on their departure from Brighton are 3 and 4 minutes.

There is a signal box at each end of the tunnel. The North Box is operated by **Brown** and the South by **Killick**. K has been working for 24 hours continuously. In his cabin, he has a clock, an alarm bell, a single needle telegraph and a handwheel with which to operate a signal 350 yards down the line. He also has red (stop) and white (go) flags for use in emergency. The telegraph has a dial with three indications: NEUTRAL, OCCUPIED and CLEAR.

When K sends a train into the tunnel, he sends an OCCUPIED signal to B. Before he sends another train, he sends an IS LINE CLEAR? request to B, to which B can respond CLEAR when the next train has emerged from the North end of the tunnel. The dial at one end of the telegraph only displays OCCUPIED or CLEAR when the appropriate key is being pressed at the other---it otherwise displays NEUTRAL.

The distant signal is to be interpreted by a train driver either as all clear or as proceed with caution. The signal is designed to return to proceed with caution as a train passes it, but if this automatic mechanism fails, it rings the alarm in K's cabin.

The accident

When train 1 passed K and entered the tunnel the automatic signal failed to work. The alarm rang in K's cabin. K first sent an OCCUPIED message to B, but then found that train 2 had passed the defective signal before he managed to reset it. K picked up the red flag and displayed it to Scott, the driver of train 2, just as his engine was entering the tunnel. He again sent an OCCUPIED signal to B.

K did not know whether train 1 was still in the tunnel. Nor did he know whether S had seen his red flag. He sent an IS LINE CLEAR? signal to B. At that moment, B saw train 1 emerge from the tunnel, and responded CLEAR. Train 3 was now proceeding with caution towards the tunnel, and K signalled all clear to the driver with his white flag.

But S had seen the red flag. He stopped in the tunnel and cautiously reversed his train to find out what was wrong from K.

Train 3 ran into the rear of Train 2 after travelling 250 yards into the tunnel, propelling Train 2 forwards for 50 yards. The chimney of the engine of Train 3 hit the roof of the tunnel 24 feet above. In all 23 passengers were killed and 176 were seriously injured.

Box 1. An account of the Clayton Tunnel Railway Accident

The physical character of the telegraph communication was unfamiliar. The telegraph signal was received in the absence of the sender, with no independent means of access to the sender or the environment in which the message was sent. The movement of a needle on Killick's dial registered as a movement of a corresponding needle on Brown's dial. The movement was a transient phenomenon, persisting only so long as Killick generated electricity from a hand-driven dynamo. In Brown's perception, it would have registered as separated from context, impersonal and potentially fragile. He needed to have faith in the reliability of the device and the authenticity of the communication.

The interpretation of the telegraph signal was dependent on a social context and protocol. The communication between K and B was intended to ensure that there was never more than one train in the tunnel at a time, but this knowledge was precariously distributed between them. K believes there is a train in the tunnel when a train enters, but has no direct means of telling when it emerges. Working practices are such that B believes the tunnel to be empty when a train emerges, but has no direct knowledge of when trains enter the tunnel. In this situation, knowledge about the state of the tunnel was inferred from the evidence of the two independent observers. This illustrates the relevance of Hutchins's concept of distributed cognition (Hutchins 1995), and his concern that "*human cognition should be seen as an activity undertaken in social settings using various kinds of tools rather than as a solitary activity*".

Putting the accident in context involves more than reconstructing the events as if from the perspective of an objective external observer (cf. Box 1). The story of the accident does not reveal potentially significant facts about what the roles of the participants involved. With what frequency did K expect trains to arrive, and to what extent was he informed about their intended schedule? How long did it take K to reset the signal? Only with knowledge of the telegraph operation is it clear that K needed both hands to send a message to Brown. Such considerations imposed physical constraints on what actions K could perform concurrently. They also raise issues about the level of robustness of the operating protocols that was regarded as acceptable: what provision was there for telegraph signalling in the event of K breaking his arm, for instance?

The actions of participants have to be understood with reference to their physical capabilities and situation. They must also be seen in relation not only to their preconceived formal protocols for interaction, but to the perceptions and expectations that evolved around them. From B's perspective, "there couldn't be two trains in the tunnel at the same time, so if a train emerged, the tunnel was empty". And for K: when a second train entered the tunnel, to create a situation unforeseen in the operational regulations, how else was he to communicate this to B except by sending an OCCUPIED signal? The way in which social order is accountable in terms of individual perceptions and protocols that emerge from practice is a particular concern of ethnomethodology (Garfinkel 1967, Coulon 1995).

Modern communications have carried the technology of the telegraph to a level of sophistication inconceivable in 1861. The impact of this development is to give even greater profile and relevance to the ontological issues that surround modern computer-mediated communication. The scope for creating alternative realities and for establishing complex relationships between one reality and another make concerns such as authenticity and the subjective-objective distinction particularly significant. In a Virtual Reality, trains can be consumed or generated in a tunnel, even though the perceptions of the signalman at its ends are unremarkable. Addressing such issues demands new frameworks for analysing computation and communication.

KNOWLEDGE AS DECLARATION – KNOWLEDGE AS EVIDENCE

Our discussion of the Clayton Tunnel railway accident highlights two very different perspectives that need to be considered in accounting for the communication between the participants. On the one hand, the accident scenario can be studied as if from the perspective of an external observer whose motivation might be to gain an objective view of the events. On the other hand, it can be seen from several independent viewpoints as through the eyes of the participants themselves. (Models of railway operation in the context of the accident, constructed from these two perspectives, will be discussed in subsequent sections of the paper.)

In point of fact, the status of an external observer is hard to establish: even the account in Box 1 is framed in terms of observations that could not possibly have been made by a single observer. There is no one witness who observed how the precise locations and speeds of the three trains involved in the accident were synchronised, for instance. Box 1 is a complex reconstruction, framed in terms of observables that for the most part are acknowledged to be objective in character (such as the movements of trains, the status of signals and the patent actions of signalmen and drivers). It also incorporates information that is private to the individual participants, and whose authenticity depends upon what is presumed to be reliable testimony and reasonable conjecture. Driver Scott lived to testify that he reversed his train because he had seen the red flag. The driver of the following train did not survive the crash, but it is more than plausible that he was observing the established standard protocol on entering the tunnel.

Where Box 1 might form part of the conclusions of the crash inquiry, the independent personal accounts of the participants would have the character of evidence. Of its essence, evidence has an open-ended quality: even after an inquiry, it is still possible to admit new evidence. The findings of an inquiry are in contrast oriented towards declared judgements and incontrovertible facts. The official account of the accident omits much that is deemed irrelevant, and attempts to arbitrate or leave conflicts unresolved as appropriate. In the process of selecting and discounting evidence, of resolving issues or leaving them open, the goals of the inquiry play a significant role. For instance, the fact that Killick had been working for 24 hours non-stop is recorded, and the time intervals between train departures from Brighton are officially declared despite conflicting evidence from independent sources.

The analysis of computation and communication is closely bound up with relating the two perspectives of the participating agents and the objective external observer. The distinction between "knowledge as evidence" and "knowledge as declaration" is particularly relevant to representing and understanding this relationship. Cognitive technology is much concerned with the potential conflict between these views of knowledge: where the human mind engages with a world of open knowledge, technology typically relies upon closed-world representations.

PARADIGMS FOR COMMUNICATION AND COMPUTATION

Longstanding ontological controversies are the backdrop for contemporary thinking on communication and computation. In constructing computer models to inform our understanding of railway operation, there are sociological and computational aspects to be considered. In sociology, the debate surrounding the place of ethnomethodology in American sociology (Coser, 1975, Zimmermann, 1976) is relevant. In computer science, the debate centres on the status of logicism (McDermott 1987, Beynon 1999).

The following quotation from Mehan and Wood (1976) frames the sociological debate:

> *Sociology studies social structures. Social structures are treated as "objective and constraining social facts". ... [controversially] Ethnomethodologists claim that the objective and constraining social structures of the world are constituted by "social structuring activities" ... Ethnomethodologists study the social structuring activities that assemble social structures.*

Coser's attack on ethnomethodology (1976) highlights the sharp discrepancy between views of sociological knowledge that underlies the controversy:

> *[Ethnomethodology] underplays the behavioural aspects of goal directed social interaction ... [ignores] institutional factors in general, and the centrality of power in social interaction in particular (p. 696) ... neglects the central area of sociological analysis which deals with latent structures (p. 698).*

Coser's concern for interpretations based on structures, goals and behaviour emphasises the declarative role of knowledge. A similar emphasis can be found in the semantic models for computation and communication that have been developed in computer science (Beynon 1999). Historical evidence suggests that the initial development of new technologies has promoted such an emphasis where both conceptions of social structure and paradigms for communication and computation are concerned. The development of railway, communications and computer technology exemplifies this.

The early influence of a technology is to stimulate the imposition of social frameworks. By way of illustration, consider the paradoxical way in which the telegraph, seen as so advanced in its time, was in some respects an unusually primitive mode of communication. Contrast the richness of the situated interactions to which railway personnel had been accustomed in the past with the abstract interaction via the telegraph. The telegraph signal is a mere symbol, detached from the context of the sender. Its communicative power depends entirely upon a preconceived framework of declared protocols. Such a technology demands social structures for its effective use.

The "transfer of responsibility from engine drivers caused by the telegraphic system of working" was the first step towards a much more comprehensive process of rationalisation that has culminated in modern fully automatic railway systems. The effect of such developments has been to eliminate the chaotic agency that operated in the early days of the railway, when people could take their own train out for the day, when signalling conventions differed from company to company, and every train was subject to frequent breakdown. The technological revolution of which the railways form a part has involved the proliferation of systems similar to a modern railway, based on infrastructures of reliable machines with which interaction follows closely prescribed rules. In such contexts, it is easy to put disproportionate emphasis on rule-based behaviour, and to overlook the importance of activity that falls outside its orbit.

The impact of early computers on our thinking about communication and computation is still strongly in evidence, arguably serving to reinforce simplistic and mechanistic views. Revolutionary as the computer has been in many respects, the central place of high-level programming and batch processing in its early history has promoted primitive paradigms for communication and rule-based views of knowledge. The influence of sequential computation and formal language theory has been to stimulate models of communication based on dialogue, and information processing theories of mind that fail to reflect the subtlety of the issues that are involved in face-to-face interaction and creative thought and action.

Social and technological developments have circumvented the problematic aspects of railway operation as it was in 1861. They have not supplied the concepts and tools needed to represent and explore these problems. To a large extent, the subtleties of informal face-to-face human communication and interaction with the environment that had to be eradicated from railway protocols are still beyond the range of our conceptual frameworks. As Coser is eager to stress, a form of science and engineering has been developed in the process, but this is not in itself enough.

As computer-mediated communications technology matures, it promises to enfranchise human interaction as rich in concurrency, situation and embodiment as we are accustomed to find in our most intimate interactions with our environment. It is in this context that the perspectives of the ethnomethodologist and the non-logicist become so significant. Both see the need to complement a scientific outlook with concern for agency, emergent behaviour and non-functional aspects of interaction. Giving a credible account of such issues is closely connected with Gooding's research (1990) into "*aspects of scientific work largely neglected by modern, especially analytical, philosophy. These are the agency of observers and the way their observation of nature is mediated by their interactions with each other, with their instrumentation and with the natural world.*".

EMPIRICAL MODELLING

Empirical Modelling (EM) (http://www.dcs.warwick.ac.uk/modelling/) has involved the development of principles, techniques and software tools for which wide-ranging application has been demonstrated. It is centrally concerned with the construction of computer-based models (known as *interactive situation models*: ISMs) that can be used to represent experiential knowledge. This section briefly outlines the main concepts of EM, and the way in which ISMs are constructed. It then discusses the use of ISMs for knowledge representation in the context of other work relating to the theme of "representing one experience by another". The justification for regarding ISMs as an appropriate foundation for such representation is discussed with particular reference to the philosophical ideas of William James (1996), the work of David Gooding on experimental science (1990) and the principles that underlie spreadsheets.

INTERACTIVE SITUATION MODELS

Empirical Modelling (EM) is an approach to computer-based modelling that is based on new principles for domain analysis and model construction. Computer models constructed using EM principles are not to be viewed as implementing an abstract mathematical model. Their significance is instead similar to that of the physical model that an experimental scientist might build to account for a phenomena, or that an engineer constructs to prototype or test a design concept. In this respect, they are distinguished from abstract computational objects that happen to be executed on a computer: the manner in which they manifest state to the user is of the essence, as is the interaction that the user can perform upon them.

An interactive situation model is so called because its interpretation is shaped by open-ended interaction with both the model and (at least, in principle) also with its referent. In EM, the construction of an ISM is seen as linked in a fundamental way to the activities that shape the modeller's insight into the referent. In particular, the modeller is concerned with construing interactions with the referent in terms of observables, dependencies and agency. There is a strong parallel between ISMs and what Gooding, in his philosophical investigations of Faraday's fundamental research into electromagnetic phenomena (Gooding 1990), terms *construals*. For Gooding, a construal is an artefact that is exploited in an explanatory and expository role.

Like a construal, an ISM implicitly represents knowledge of an evidential nature. Because of the way it is conceived and built, an ISM does more than simulate a particular behaviour of its referent. The knowledge of observables, dependency and agency that informs its construction is acquired though experiment. Unlike a conventional computer program, which has a preconceived and formally specified behaviour, an ISM is open to interaction in a manner that includes the experimental contexts used to construct it. The significance of EM is that it offers principles to account for how one experience represents another: principles that can be used both to validate such a representation and to create one.

THE CONSTRUCTION OF INTERACTIVE SITUATION MODELS

An ISM is described by a family of definitions (a *definitive script*). The LHS of each definition is a variable that represents an observable; the RHS is a formula that expresses how the value of the observable on the LHS is perceived to be functionally dependent upon the observables referenced on the RHS. The variables on the LHS of the script in general have visual (or otherwise perceptible) counterparts. Figure 1, for instance, is defined by a script in which many of the variables represent points, lines, windows or characters that determine the layout and content of the computer screen.

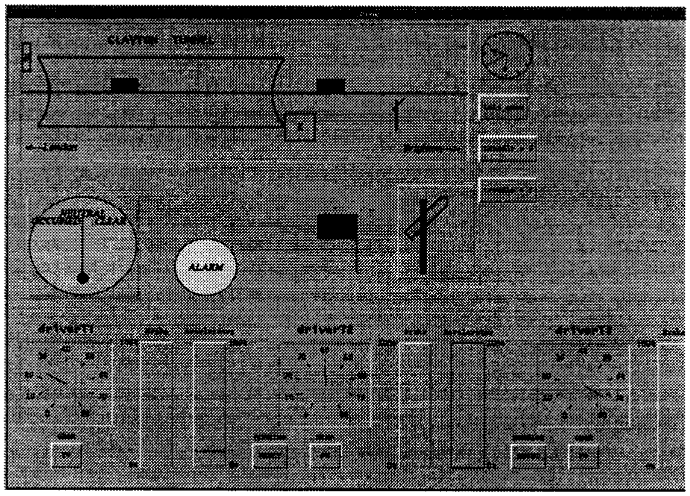

Figure 1. An external observer's view of the Clayton Tunnel

The ISM is properly associated not merely with a single script, but with an open-ended space of scripts that can be derived from any particular instance of the script through meaningful interaction. This closely resembles the way in which we regard a spreadsheet as describing the financial situation of a company, on the understanding that the current values in the spreadsheet represent the present financial situation, and other possible values (yet to be encountered or conceived) might be entered to reflect a change in the financial situation (whether real or putative).

The observables in a script will typically be grouped into families of attributes associated with particular agents. The word 'agent' is used in EM to refer to any family of observables that can be construed as associated with a coherent identity. There may be no autonomous action that is attributed to such an agent, in which case it can be regarded as an object in the commonsense (rather than the technical computer science) meaning of the term. In conventional programming for simulation, it is vital to arbitrate about the status of objects in respect of agency at an early stage in the design - the representation of program state demands this as a prerequisite. In EM, state-transitions and agency are the subject of negotiation and design, and remain fluid at every stage. A radical shift in perspective is needed to interpret computer-based modelling of this nature.

ONE EXPERIENCE KNOWS ANOTHER

An ISM represents its referent in the sense that one experience can represent another. Precedents for this concept can be found in the writings of William James on his Essays on Radical Empiricism (1996, Beynon 1999). In his essay The World of Pure Experience

(1996, p39), for instance, he discusses "the ways in which one experience can function as the knower of another". Turner's account of the how our minds habitually blend one story with another (1996), and Gooding's analysis of construals in experimental science (1990) develop a related theme. In every case, these concepts are motivated by much more than mere informal imitation of a behaviour that is to found in computer simulation, or the semi-formal use of standard Unified Modelling Language artefacts for software development (Pooley 1999). James proposes Radical Empiricism as a new philosophic attitude. Turner (1996, p140) proposes parable as an alternative to the dominant contemporary theory of the origin of language. Construals are fundamental to Gooding's new approach to the problems of empirical access in the philosophy of science (1990, xii).

All these approaches have in common a concern with explanation, with the processes of knowledge creation, and with the manner in which meaning is negotiated through interaction. Where formalisms aim at freedom from ambiguity and independence of agency and context, experiential representations rely essentially upon the engagement of the human interpreter. As Gooding states (1990, p87): "*a construal cannot be grasped independently of the exploratory behaviour that produces it or the ostensive practices whereby the observer tries to convey it*". This presents a serious difficulty in communication with those who contend that what is meaningful can be formalised. It is a difficulty that cannot be resolved without recourse to new universally recognisable intuitions.

The thrust of James's Radical Empiricism (James 1996) is to identify intuitions that can supply a foundation for the study of experiential knowledge. A central idea in this "philosophic attitude" is that certain kinds of conjunctions must be acknowledged as empirically given. One example of such a *conjunctive relation* is "*the co-conscious transition, by which one experience passes into another when both belong to the same self*" (p47). A more discriminating conjunctive relation is *continuous transition* (p49): "*when a later moment of my experience succeeds an earlier one ... though they are two moments, the transition from the one to the other is continuous*".

Continuous transition is precisely the intuition to which we appeal when referring to "the spreadsheet that represents the financial situation of a company". More generally, what James identifies as "*the relation experienced between terms that form states of mind*" (James 1996, p45) is what guides us in joining together the observables that are represented in the cells of the spreadsheet. Where Radical Empiricism treats all such conjunctive relations as primitive, traditional empiricism recognises conjunction only as *withness*.

James draws particular attention to the chaotic way in which conjunctive relations are disposed in our experience. The observables associated with any given situation can participate in countless states of mind, for instance. A single spreadsheet may be used to record the actual financial status of a company, to speculate about future states, or adapted to model the financial status of many companies. It can also be viewed as a piece of software, and evaluated for efficiency or correctness.

THE SEMANTICS OF INTERACTIVE SITUATION MODELS

James's account of Radical Empiricism clearly articulates how experience leads to the identification of conjunctive relations. With reference to the primitive disjunctions and conjunctions encountered in our experience, he writes: "*Radical Empiricism .. is fair to both the unity and the disconnection ... [it agrees] that there appear to be actual forces at work which tend, as time goes on, to make the unity greater.*" (James 1996, p47) The empirical process by which we come to recognise the identity of features and the integrity of objects presumably lie within the scope of this account. James does not explicitly identify dependencies as conjunctive relations, but this classification seems entirely appropriate. The psychological claim being made here is that, through experience of interaction with observables, we come to apprehend the dependencies between them with the same immediacy that we apprehend identities and integrities.

Empirical Modelling places particular emphasis on the identification of dependencies as a basis for analysing and representing experience. There is much informal evidence to justify such an emphasis. Dependencies between observables have a central place in experimental science, where the aim of an experiment is frequently to demonstrate the predictable effect of changing the value of one observable upon that of another. Mathematical insight is often associated with the identification of dependencies, as is illustrated by the impact that abstracting trigonometric ratios had upon in land measurement. The psychological congeniality of applying spreadsheet principles is well-recognised.

In summary, the concept of an ISM can be seen as a synthesis of key ideas from several sources. An ISM incorporates dependencies that resemble, but are more general than those in a spreadsheet. It is an artefact to be experienced and exploited in much the same way as a construal, in Gooding's sense. In particular, the embodiment of dependencies is significant, and its interpretation is shaped through the observer's interaction. Being computer-based, an ISM has far greater potential for metamorphosis than traditional construals. Its function is to support the empirical processes by which conjunctive relations are identified and organised. In this connection, the identification of dependencies has a primary and fundamental role.

COMMUNICATION: AN EMPIRICAL MODELLING PERSPECTIVE

This section examines how EM addresses the issues concerning communication raised in Section 1. The railway accident case-study illustrates how ISMs can be used to represent railway operation from two perspectives: as if from the viewpoint of an external observer, and from the viewpoints of the participating agents. The characteristic state-based nature of this representation of an individual perspective is first elaborated. The distinction between a conventional simulation and a simulation based on ISMs is also discussed.

HOW INTERACTIVE SITUATION MODELS REPRESENT STATE

Figures 1 and 2 are screenshots taken from two related computer models that have been created using EM techniques and tools. Figure 1 is based on an ISM that has been constructed as if from the perspective of an external observer. Figure 2 depicts an exercise in distributed EM, in which several ISMs are used concurrently by independent modellers based on different workstations that are networked in a client-server configuration. Both of these computer models can be used to animate aspects of railway operation, including the accident scenario, but they also serve wider purposes. For instance, they can be used - separately or in conjunction - to investigate issues pertaining to the circumstances of the accident, and to deal in particular with those aspects of communication between agents that are difficult to address by other methods.

In representing one experience by another, EM is not primarily concerned with simulating particular behaviours in the orthodox sense. The emphasis is closer to that of the experimental or forensic scientist, who is typically concerned with analysing the local and immediate effects of limited interactions abstracted from the domain or system as a whole. In the same spirit, the *what-if?* in a spreadsheet is concerned with what happens on performing a certain action in a certain state.

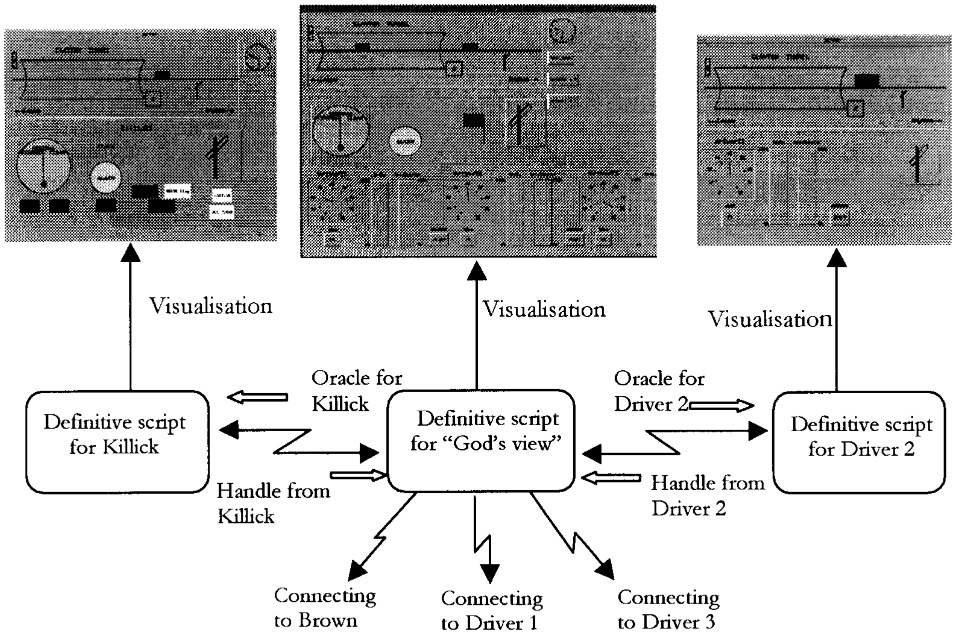

Figure 2. Distributed Empirical Modelling using EDEN

The idea that the state of an ISM represents the state of its referent may superficially seem unremarkable, but requires further consideration. It is clear that the representation of one experience by another is essentially a matter for one mind. The archetypal picture of the Empirical Modeller is that of an agent in the role of experimenter who in parallel consults and interacts with the state of an ISM and the corresponding state of its external referent (see Figure 3). What is meant by the state of the computer model may seem self-evident when we refer to a single ISM (as in Figure 1), but it is by no means clear that the concept is appropriate when the computer model is distributed and there are several independent modellers (as in Figure 2).

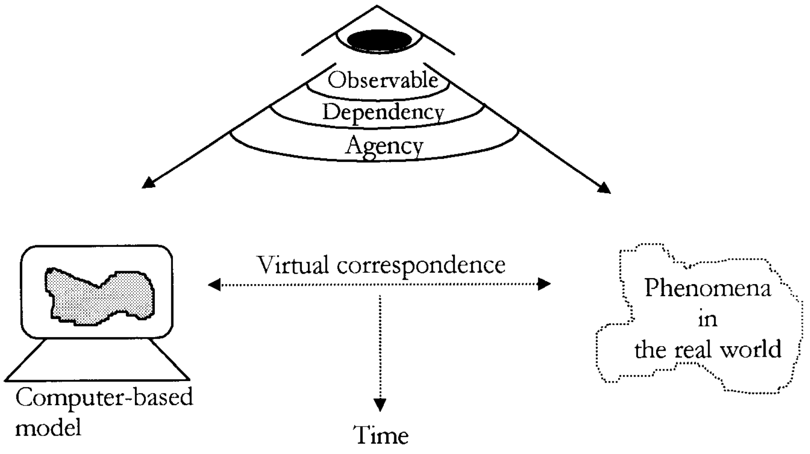

Figure 3 The Empirical Modeller as experimenter

The perception of state is central to the ontological controversies alluded to in Section 1. Relevant issues are raised by considering both the state of the referent and that of the model. Though Figure 1 may appear to reference a global state in the referent, it is not clear *whose* apprehension of state, and it does not correspond to any participant in the railway operation. If we look upon knowledge of the world as given by structure that transcends any particular viewpoint, then we may suppose that some such view abstractly exists. Even this supposition has little relevance for EM, since it is quite obscure in what sense the modeller has empirical access to this 'objective' view.

Similar concerns pertain to the state of the computer model in Figure 1. The state of a computer model is commonly viewed as explicitly and concretely specified by the abstract values assigned to variables in the execution of a program, but it is not to this concept of computer state that EM activity refers. The experience associated with an ISM patently depends upon particular characteristics of hardware and software, and the power to create illusion. The dependency update is not instantaneous, nor is the update of the screen; the motion of the train icons across the screen is not continuous both on account of pixelation and the sampling of the train positions for the purpose of display. The perceptual perspective of the modeller is a complementary concern: these illusions are effective because of physical characteristics and capabilities of the person engaged in the interaction, and their ability to appreciate certain conventions.

The impact of this discussion is to demonstrate that Empirical Modelling is essentially concerned with activities that demand extra-logical intuitions of the kind proposed by James. To apprehend state is to apprehend a conjunctive relation. The whole process of interacting with the ISM and with its referent is a negotiation in which the integrity of state is shaped and challenged. The presence of formal ingredients in an ISM, such as the symbolic information about the status of the telegraph, should not obscure the fact that the essence of EM is experiential. The role of such ingredients resembles that of the textual annotations and labels attached to the objects in a political cartoon: they enable us to identify the referent, but are in other respects incidental to the blend of experiences that makes the cartoon meaningful (cf. Turner 1999).

The nature of EM and of ISMs will be illustrated in subsequent sections with reference to railway operation in the vicinity of the Clayton Tunnel. By way of introduction, it is useful to examine the issues that surround the construction of ISMs more closely. From the orthodox formal computer science perspective, it is difficult to understand how it is possible to mould an ISM when its behaviour is not conceived and specified with reference to an abstract mathematical model. It is not even appropriate to regard an ISM as mathematically specified at the program code level, since its representational power depends in an essential way upon non-functional considerations, such as the speed of execution and the quality of the graphical display. The software tools we have so far constructed for EM demonstrate that the proper conceptual framework for ISM construction is itself based around families of observables, dependencies and concurrently acting agents. Empirically validated procedures for dependency maintenance and strategies for scheduling agent action are central to successful implementation. Richer mechanisms for user interaction are a complementary concern that has yet to be effectively addressed. The aspiration for such tools is closer to 'making an instrument' than 'implementing a program'.

The status of distributed EM is particularly intriguing in this regard. The EDEN interpreter allows several modellers, using independent workstations and each developing an ISM from their personal perspective, to co-operate in a client-server framework. In such an open architecture, there are even fewer guarantees about synchronisation of action and integrity of state than can be given when constructing an ISM using EDEN on a single machine. The concept of orchestrating interaction with the model to empirically establish appropriate conjunctive relations is nonetheless pertinent, though this reflects social and organisational considerations as well as hardware and software issues. In particular, the physical arrangement of workstations is significant. For instance, when studying the Clayton Tunnel accident scenario with schoolchildren in the roles of signalmen and drivers, the disposition of their workstations affected their appreciation of notions such as "trains travelling from Brighton to London".

EMPIRICAL MODELLING FOR THE EXTERNAL OBSERVER

The protection afforded to a modern day driver who enters the Clayton tunnel is no doubt very different in character from that conceived in 1861. The signals that prevent a driver from entering the tunnel whilst it is occupied will be automatically set to caution and all clear as preceding trains enter and leave critical track segments. The event-driven switching involved in such a process is entirely different in character from the activity in which K participated. For K, there was no one instant in time at which the train arrived at the tunnel: the arrival of the train was associated with an evolving state, hearing a distant whistle, seeing the smoke of the train, hearing the engine puffing, watching the train approach. In James's sense, this was a continuous transition, though in physical terms it may have involved suspension ("K hears the whistle") and resumption (some time later - "K sees the smoke").

The relationship between these two modes of communication serves to highlight the distinction between a simulation based on the use of an ISM and a simulation specified by a conventional program, or formal model of event sequences. A switch on the track is quite oblivious to the glorious prelude to the passing of a steam train; it records only a binary signal that is optimised to perform its function because the context in which it operates is so tightly constrained by engineering and by social conventions and regulations. Whilst K knows that the train has gone past him, the switch simply resets to its original state. K could distinguish between a real train and a heavy object falling on the track in such a way as to activate the switch. The switching and signalling technology exploits an optimised model of a controlled environment that is limited to sparse abstract events and aggregations of primitive states.

In designing a conventional program for simulation purposes, the process of identifying the precise family of significant events and relevant observables has to be carried out. This process must presume knowledge of the goal and scope of the simulation. The interpretation of the program, and its effect on its environment, is conceived and determined at the point of design.

In contrast, the role of an ISM is not in the first instance to prescribe a pattern of activity to suit a particular function, but to track an evolving state of mind. For the ISM pictured in Figure 1, this is the state of mind of the external observer, who tries to imagine the interaction between the agents in the system, and their corporate effect, from an objective viewpoint. This ISM reflects the way in which the external observer construes railway operation to occur, but is not primarily expressed based on the preconceived 'significant events' in the railway protocol.

To illustrated this, consider how the ISM associated with Figure 1 can be used to investigate scenarios relating to the accident . Metaphorically, Figure 1 discloses how far an approaching train is from K, enabling the external observer to speculate on when it is first audible or visible to K. It provides insight into when a driver, having seen a signal at caution, might apply the brake, and - taking account of different presumptions about the train speed and braking efficiency - where the train would come to rest. This gives the external observer a model of state that captures much more than the instantaneous events that are preordained to be important in a structured behaviour. Even events that are not significant in railway operation terms, but might be useful evidence to a crash inquiry, such as the knowledge that a train driver waved to K, can be attributed to a state and have their effects registered.

Two modes of generating state-transitions in the ISM are useful in this connection. Where appropriate, certain predictable state-changes can be implemented by automating the redefinition of observables. In typical interaction with the ISM in Figure 1, the mechanics of train motion is handled in this fashion. Alternatively, when it is necessary to emulate state-changes that in some respect are unpredictable, the external observer can intervene directly to simulate the redefinition of observables. The failure of the treadle to reset the signal can be modelled in this way, as can the telegraph communication between the signalmen.

Such modelling can give insight into both those aspects of communication in the accident scenario that are characteristic of face-to-face communication and to informal situated human interaction outside the scope of structured social contexts and conventions (cf. Section 1). By adapting and interacting with the ISM in different ways, it is possible to assess the maximum frequency and speeds at which trains pass through the tunnel, to consider the implications of different weather conditions and train malfunctions, and to model the consequences of actions on the part of railway personnel that do not conform to fixed rules and schedules.

EMPIRICAL MODELLING AND ETHNOMETHODOLOGY

Modelling state as if from the perspective of an external observer is one aspect of the use of ISMs. The apprehension of such a state is a very sophisticated activity that is essentially tied up with construing state change in the world and the social interaction that surrounds it. For a particular observer to adopt such a perspective involves identifying agents and the observables that mediate their agency, and attributing an intersubjective status to such observables. A fuller discussion of how EM engages with this projection from personal to second and third person viewpoints is given in (Beynon 1999). At no point can the correspondence between the ISM and its referent be anywhere other than in one mind, but this does not preclude such classification of observables. In the words of James: "*subjectivity and objectivity are affairs not of what experience is aboriginally made of, but of its classification*" (James 1996, p141).

As distributed cognition and ethnomethodology both advocate, to appreciate the interactions in a complex social system such as a railway it is necessary to consider the "states of mind" and the "conjunctive relations extant within the states of mind" of the state-changing agents in a system. Figure 2 depicts the way in which concurrent interaction of several user-modellers each with their own private ISMs can be used for this purpose. The EDEN client-server architecture is used for this purpose: the viewpoint of each participant being reflected on a separate workstation, and communication between agents expressed through the transmission of definitions between clients.

In the distributed EM environment, it is possible to respect Hutchins's concern (1995) for examining activity in its social setting. In accordance with the aims of ethnomethodology, communication can be studied from the being-a-participant perspective, and there is scope to explore "the social structuring activities that assemble social structures". As Figure 2 indicates, the private views of the participants in the railway operation can be more faithfully represented and clearly distinguished. Since K cannot see a train that has entered the tunnel, its iconic representation on K's workstation disappears as it enters the tunnel. The distributed environment is engineered so that the state-changing actions that each participant is able to carry out can be interactively shaped to reflect their capabilities.

In the distributed model, the perspective of the external observer ("God's view") is reflected at the server. The server has a number of roles: it provides the environment for the experimenter who wishes to study the communication between the participating agents; it also provides the platform for the activities that can be used, where appropriate, to monitor and restore the integrity of the viewpoints. Since each agent has an independent viewpoint, there is scope for knowledge representation that entails realistic inconsistency and subtlety. For instance, whereas in an event-oriented framework "K waves the red flag at S" would typically be understood as a communication from K to S with preconceived implications for K and S, it is possible to reflect the distinction between "K waves the red flag" and "S sees the red flag".

The development and application of distributed EM, though still at an early stage, raises many promising avenues for further research. Our experience of simulating railway operations with schoolchildren in the role of signalmen and drivers proved very helpful in enabling us to assess the plausibility of the assumptions that had to be made in reconstructing the accident scenario. These confirm the advantages of being able to see events from each participant's perspective.

The shaping of social reality with which ethnomethodology is concerned is central to many technical issues for distributed EM. Mediating between the perceptions of the participants is a fundamental aspect of the server's role that has practical implications for the way in which communication between clients is organised, and for the way in which investigation of the model is conducted. In this connection, there is an essential need to take account of those elements that the participants presume to have objective status. Though this is not at present explicitly modelled by an ISM, each human agent is influenced by some preconceptions about the global view, albeit often imperfect and incomplete. By way of illustration, even though B caught only a brief glimpse of the trains that travelled from Brighton to London, he projected approaching trains in his imagination, and would have been concerned at the absence of trains emerging from the tunnel following the accident.

CONCLUSIONS

Major research efforts worldwide are currently being directed at ambitious technical work on generating new virtual environments, and complementary investigations into their psychological qualities and social implications. To exploit and understand these developments most effectively, it will be vital to provide some supporting principles.

Finding such principles will involve new ways of thinking about communication and computation, quite different in character from those that have been emphasised in the past - and that were most appropriate to the technologies of the time. Consolidating upon the ideas of James, Turner and Gooding on "using one experience to represent another" has an essential part to play.

Brown and Killick, pioneers in the age of networked minds, were innocent of the subtleties of the communicative framework surrounding them. It is hard to judge to what extent we are better prepared for the potential pitfalls of communication in virtual worlds and understand its potential influence over our cognitive processes. In James's account of knowledge (1996, p83), *Space* is the fundamental object that our minds hold in common, and touch is its arbiter. It remains to be seen how far from the clasp of hands is the meeting of networked minds.

REFERENCES

Adzhiev, V.D., Beynon,W.M., Cartwright, A.J., & Yung, Y.P. (1994). A computational model for multi-agent interaction in concurrent engineering. *In Proc. CEEDA'94*, 227-232.

Beynon, W.M. (1999). Empirical Modelling and the foundation of artificial intelligence. In C. Nehaniv (ed), *Computation for metaphors, analogy, and agents*, Lecture notes in AI, 1562:322-364.

Coser, L (1975). Presidential address: Two methods in search of a substance. *American Sociological Review*, 40(6), 691-700.

Coulon, A. (1995). *Ethnomethodology*, translated from French by J. Coulon and J. Katz, SAGE Publications.

Garfinkel, H. (1967). *Studies in ethnomethodology*, N.J., Prentice-Hall.

Galegher, J., & Kraut, R.E. (1994). Computer-mediated Communication for Intellectual Teamwork: An Experiment in Group Writing. *Information Systems Research*, V5(2), 110-138.

Gooding, D. (1990). *Experiment and the making of meaning*, Kluwer Academic Publishers.

Hutchins, E. (1995). *Cognition in the Wild*. MIT Press.

James, W. (1996). *Essays in Radical Empiricism*. Bison Books.

McDermott, D. (1987) A critique of pure reason. *Comput intell*, 3:151-160.

Mehan, H., & Wood, H. (1976). De-secting ethnomethodology. *American Sociologist*, 11, 13-21.

Pooley, R.J. (1999). *Using UML: software engineering with objects and components*, Addison-Wesley.

Rolt, L.T.C. (1982). *Red for danger*. Pan Books, 4th edition.

Sonnenwald, D.H. (1993). *Communication in Design*. PhD thesis, The State University of New Jersey.

Turner, M. (1996). *The Literary Mind*. Oxford University Press.

Turner, .M. (1999). Forging connections. In C. Nehaniv (ed), *Computation for metaphors, analogy, and agents*, Lecture notes in AI, 1562:11-26.

Zimmerman, D. H., (1976). A reply to professor Coser. *American Sociologist*, 11, 4-13.