The Use of Interactive Situation Models for the Development of Business Solutions

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Abstract

An interactive situation model (ISM) is a novel computer artefact used to represent state-as-experienced. The meaning of an ISM is the perceived association between the state of the ISM and the state of its real-world referent during arbitrary interactions. The concept leads to a quality of modelling radically different from conventional computer-based modelling. This is illustrated by ISMs for timetabling, railway operation, warehouse and restaurant management. This approach to modelling represents a paradigm shift from a 'method-tool-user' culture to one where the computer-as-agent integrates more closely and flexibly with human and business activities.

Keywords: modelling, information systems, decision support systems

1.0 Introduction

The concept of an *interactive situation model* (ISM), introduced in a recent PhD thesis by Sun [Sun99], is based on novel technical principles and is well-suited to application in the business environment.

Existing technologies for the support of information systems (programming, databases, GUIs, network protocols etc) usually impose a separation between the user's experience of a business area (such as product development or marketing) and the user's experience of the computer-based model or tool intended to support that area. For example, it may be the selection of a particular data type, or data format (required by programming conventions) which does not match well with the data as it is experienced. Or there may be the pre-conception of the allowed interactions with the model via a menu-system, which may be satisfactory for routine tasks but which renders the system useless in the face of unusual or unforeseen events. This separation between experiences of the real world and of the model may be less of a problem in scientific or engineering applications where there is a long tradition of successful application of theories and abstract entities. But in the business environment such a separation leads to major problems: it is hard to enhance models incrementally in line with further experience, it is hard to add or apply contextual information appropriate to different situations, it is hard for end-users (managers) to modify the models. The purpose of the research described in this paper is to address these problems (amongst others) by reducing significantly the separation in kind between experience of the world and experience of the model.

The construction of an ISM proceeds according to the principles and tools of Empirical Modelling (EM, so-called because based on observation and experiment)[EMweb]. The main idea of EM is to complement symbol-based models (e.g. equational, or logical models, which do not offer any direct experience) with models which present the user with experiences of interaction which can be directly compared with real-world experiences. Given the limitations of current interfaces such interactive experience often needs to be mediated by metaphors (e.g. icons) rather than by a 'virtual reality' style of experience.

The central activity of EM is the building of computer-based artefacts that present to the user the key observables of a domain in a way that the user will readily recognise them (because they are close to the way they are experienced in the real world). Certain changes in the observables follow an indivisible 'law-like' pattern (due to physical properties, conventions etc), and these are expressed in dependencies that are automatically maintained by EM tools. Other changes occur by direct, unpredictable intervention by agents. The principles of identifying the relevant observables, dependencies and agents are prominent in the analysis process and they inform the proper use of EM tools.

A business ISM is developed through a series of experiments comparing interactions with the model with interactions with the real world. It is a learning process for the modeller in which the model forms an extension of their mental model of a business process. This makes for a rich quality of interaction and an unusual openness in the emerging model. The inclusion of 'situation' in the term ISM is related to 'situated action' in the sense used by Suchman [Suc87]. An ISM – especially in the early stages of development – is a provisional and subjective model with the 'here and now' character of a particular situation well known to the modeller. We believe these properties of openness and situatedness reduce the separation of model and world referred to above and offer the possibility of a user deriving qualitative knowledge of the world through interactive use of the model. Furthermore, an EM approach achieves important kinds of integration in the construction of a business ISM: both formal and informal knowledge are included, analysis and design processes are intertwined, and interface issues are made integral to the system.

Decision making is a central part of business practice at every level of management. Sutherland [Sut89] classifies three levels of decision making: strategic, tactical and operational. The strategic level has to do with formulating and choosing among alternatives that are different in kind ('qualitatively disparate'). A decision support system is one in which the human user plays an essential, interactive role. This makes the integration, and the qualitative nature, of an EM approach particularly suited to a strategic decision support system. The paper includes some discussion and illustration of how ISMs can be used in strategic decision support.

2.0 Interactive Situation Models

2.1 Matters of State

The concept of an interactive situation model is motivated by thinking about state. The word 'state' is here used to refer to what we understand personally as pertaining to the present. It is apparent that there is no simple interpretation of what might be described as a state in any particular setting. As of now, I may meaningfully talk of my state of mind, the state of the world, the state of my neighbour's garden, the state of my finances. The philosophical orientation that best suits this view of state is discussed in depth elsewhere [Bey99], with particular reference to the ideas of William James [Jam12]. The emphases to be borne in mind in the informal discussion of state that follows are:

- state is to be seen as state-as-experienced: it is framed by what a person is currently aware of in their environment, and is subject to continuous change.
- state derives from a perceived integrity, an identity that persists through change. My mind, the world, my neighbour's garden, my finances are examples of such identities.
- states are associated with many different possible foci of attention. In concentration, a single continuous thread of state-change can preoccupy us. Our attention is directed at an integrity, and relates to one and the same identity. The possible foci of attention that establish current states in our experience are potentially concurrent, and are disposed in a quite chaotic and incoherent fashion, as typically becomes evident when we are distracted.

The concept of state being invoked here is very different from the formal concept of computational state. It does not have the discrete and precise quality of the states in an abstract automaton such as a Turing machine, a statechart, or a Petri net. It is perfectly possible to think of the state of being distracted, for instance, in which two foci of attention are competing for attention. No plausible model of my state of mind can neglect the many latent states that lurk in my subconscious but are primed to intrude on cue. The theoretical scientist's view of the current state of a physical system is similarly limited. The dynamics of a clock pendulum in motion make no reference to its rich metallic colour, nor to the significance of the impending stroke of midnight.

States in the business environment are not typically well-suited to representation by mathematical models. It is scarcely possible to identify abstractly the factors that shape the manager's perception of the state of the business, that persuade a customer to buy a product, or determine the cost of its components. The kinds of modelling activity that have been applied to such issues are different in character from classical scientific or computational models. They typically involve consultation with many interested parties, the development of physical artefacts in the form of annotated graphical charts or prototype products, and of computational models based around databases and spreadsheets. The interactive situation model is a generic term that can encompass models of this nature.

2.2 About Interactive Situation Models

An interactive situation model (ISM) is a computer-based artefact that is used to represent state-as-experienced. Its interpretation is not fixed in the mind of the modeller, but is dynamically shaped through interaction with the model, and with direct reference to its associated situation (the *referent*). No formal semantics is invoked - it is simply that the modeller perceives that the state of the ISM accords with the state of the referent. This perceived association between a state of the ISM and a state of the referent - the *semantic relation* - is to be treated as an irreducible feature of human experience. (It is viewed as an example of a 'conjunctive relation' in the sense of William James [Jam12].) The significance of the values in the cells of a spreadsheet is acquired through such a semantic relation, as is that of pictorial elements in a representational painting. The preservation of the semantic relation is essential in all meaningful interaction with the ISM - if the semantic relation is obscured or broken the significance of the state of the ISM is diminished or lost.

Within the computational framework of EM, the current state of an ISM is described by a family of definitions, or *definitive script*. The variables in these definitions correspond to *observables* in the referent, where the term *observable* is used in a broad sense to include any aspect of the current state of the referent to which an integrity and identity can be ascribed. Unlike conventional mathematical or program variables, the variables in a definitive script are like real-world observables in important respects. For instance, they can typically be apprehended in many ways, and so can have several accessible representations within the model. By way of illustration, I can observe the real-world time by looking at a clock, consulting a sundial, or listening to a chime, and can represent the time in an ISM by maintaining a variable whose value is the system time, by linking the system time to a digital watch display on the screen, or to a point on a timeline.

Interaction with the ISM involves a characteristic state-based orientation towards the referent. Since the modelling activity is conducted as if it were taking place in the presence of the referent, the set of observables in the referent that are currently captured in the ISM is regarded as at all times extensible. This is in stark contrast with conventional computational or mathematical modelling, where the emphasis is upon behaviours in the referent, and the family of observables represented in the model at any point is not open to dynamic extension, but is confined to selected observables relevant to the particular function of the model. The modeller's primary interactions with the ISM take the form of introducing new observables or dependencies and assigning new values or dependencies to existing observables. Such interactions can serve many different purposes, and are subject to different interpretation according to the particular situation and present intentions of the modeller.

The most primitive and characteristic form of interaction that an ISM supports is the *what if?* experiment. Such interactions are used in conjunction with knowledge of the referent to guide the interpretation of the ISM. Knowledge of the referent may involve commonsense, direct observation, or experiment on the referent. Some interactions respect the semantic relation, some enhance it, others violate it. Creative use of the ISM necessarily involves interactions that - like informative but 'unsuccessful' scientific experiments - visit states where the semantic relation is lost or obscured. Experimental interactions help to identify dependencies, and to determine the scope of personal agency. When the semantic relation is found to be respected reliably in the neighbourhood of a state, local behaviours can emerge. These local behaviours are represented by sequences of definitions in the ISM. Observed state changes in the referent can sometimes be attributed to other agents that act through performing such sequences of definitions autonomously or in response to recognisable cues.

The Empirical Modelling approach originates in the use of ISMs for the representation of personally apprehended state, and can be elaborated in many different ways. The concurrent use of several definitive scripts can be used to reflect the presence of several states latent within a state of mind. The use of visualisation and of direct manipulation techniques at the interface can convey qualitative characteristics of a referent. Similar features allow an ISM to serve as an instrument. The views of many different human agents can be represented through distributed ISMs (as in [Sun98]), in which communication is effected through transmitting definitions between the nodes of a computer network. The link between interaction with ISMs and conventional mathematical modelling, where the observables are to be viewed as abstract and objective, is more difficult to trace. It involves an ontological reorientation that is discussed in detail in [Bey99], and has been illustrated in connection with the formal specification of the heapsort algorithm in [BRS99]. More characteristic applications of ISMs, oriented towards business applications, are the subject of the case-studies in section 3 below.

2.3 State-changing in a business context

The states and state changes that characterise a business process are often meaningful only in relation to a very specific situation. The procedures that different supermarkets follow at the checkout will vary according to whether they have a customer loyalty card scheme, when and how this card can be redeemed, whether they give a discount for the use of customers' shopping bags, whether they have a cashback scheme, whether they give petrol vouchers, whether they print cheques and so on. Different procedures may refer to roles that have no counterpart in another supermarket chain, and to staff management practices and incentives that are as various as the checkout protocol itself. Such diversity distinguishes a business process from the processes that a physicist studies, which are more generic and abstract in their form and application. The highly situated nature of business processes makes mathematical modelling less appropriate. This is one motivation for introducing interactive situation models.

The common feature that unifies business processes with abstract physical processes is the stability and reliability of the experience to which they refer. The practices of my local supermarket may be particular to the branch or chain, but they occur in a setting that is so well-regulated that it has a predictable, ritual quality. The aspiration of business management is to establish environments and routines that operate according to conventions and protocols as reliable as scientific laws. In applying ISMs in business modelling, the principal idea is to invoke science as an experimental rather than a theoretical discipline. Whilst checkout procedures at my local supermarket cannot be specified adequately by abstract laws, they are accountable in terms of patterns of observation, dependency and agency that - though specific to their context - are for the most part reliable.

A shift in perspective is invoked in developing ISMs: from the business process as specified by an abstract pattern to the business process as developed from a situated activity. As an abstract pattern, a business process may be represented from a computational perspective by a formal state-transition model, such as a statechart or Petri Net, and from a management perspective, by a collection of rules that define the roles of human participants. Neither specification is deeply engaged with the actual experiences involved in carrying out the process. Abstract computational states and business process rules refer to interactions and situations that are presumed to be so well-understood that the observations and actions to which they correspond can be specified without considering their particular setting. The knowledge about the business process and situation that is engaged when using such models is intrinsic, and its validity depends essentially upon presumptions about quality, topicality and comprehensiveness of the experience that underpins the model.

There are several powerful motivations for seeking more situated models of business processes. Maintaining continuity and stability is problematic in the business environment. New technologies and working practices are common (e.g. e-commerce, computerised stock control, 24 hour service regimes), unexpected and irrevocable events are commonplace (e.g. loss of key staff, mergers, financial crises), and patterns of activity that are stable can be influenced by factors that are appear unrelated (e.g. a sales routine that has been highly successful may fail as fashions change). Insight into how abstract business process models are embodied in their environment is needed to address key questions. How is the business process affected by environmental change? How can I take account of more factors in the business process, such as how it affects particular staff? To what extent are the rules of a business process being observed, and to what extent is it practically feasible to follow them?

The aspiration of EM is to provide a framework within which to examine such issues. In this framework, ISMs are used to represent the way in which business activities are construed as operating. The aim in using this representation is first to model the agents, observables and dependencies that operate in the business environment, then to explore the way in which these frame the reliable patterns of interaction that underpin effective business processes. In its orientation and use of artefacts, our approach resembles the so-called "scientific method". In neither case is the term "method" appropriate, since there is no systematic procedure that can predict which experiments it is most appropriate to perform at any point, and which will yield new insights into observation, agency and dependency. For this reason, no claim is made about whether it is possible to give effective answers to the key questions in any particular situation. If any claim is appropriate, it is that the explanations for process behaviour that are being sought accord well with characteristic commonsense explanations.

3.0 ISMs for Business Applications

An ISM relies upon an explicit representation of state that involves the selection of certain observables. The term 'representation' should be understood in the broad sense in which it is used in speaking of a painting as a representation. The potential - indeed inevitable - incompleteness of this representation is recognised. Each state-as-experienced is more than any representation of it. Figure 1 depicts the semantic relation as an association between the state of a computer-based ISM with the state of an external referent. The possibility for unbounded extension of the family of observables involved in establishing this association is reflected in the open-ended script.

The open-endedness of the script in Figure 1 is important in many different applications. Teaching and acquiring skills often involves drawing attention to observables whose presence and significance is at first unrecognised. The development of scientific theories is centrally concerned with determining when and whether what we observe is sufficient to characterise a phenomenon. History shows that what observables are seen as significant in describing a real-world phenomenon changes with time and fashion. For instance, in fields such as medicine, advances in instruments and under

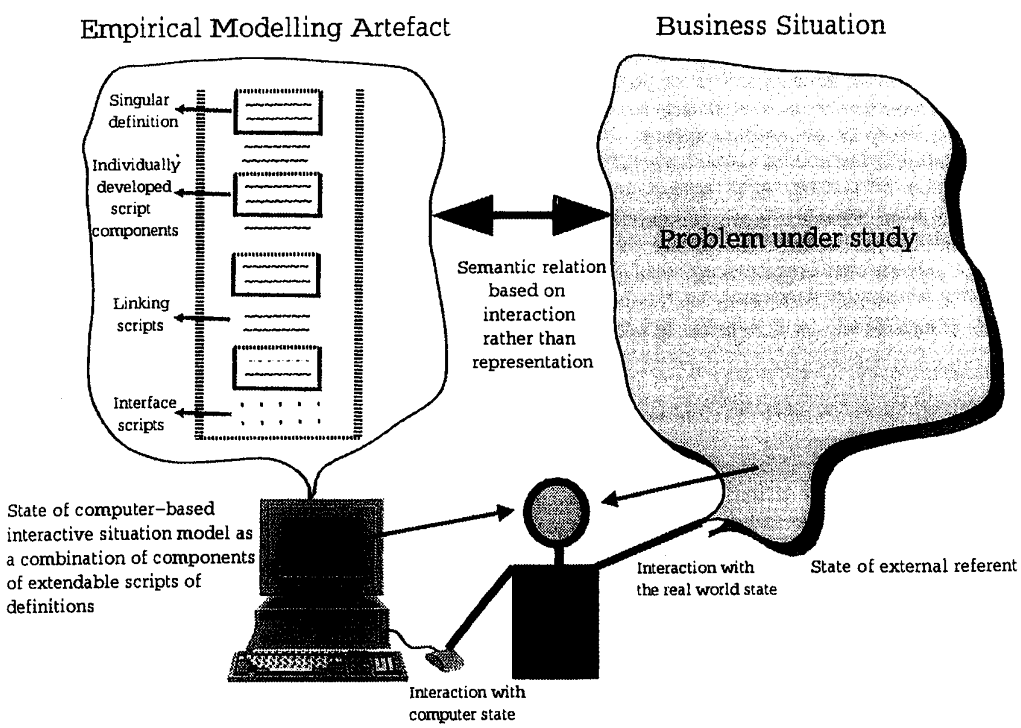

FIGURE 1. Open-ended Modelling with Scripts

standing introduce new observables, and eliminate the need for observation that is associated with obsolete explanations.

This section gives a brief account of several different ways in which the framework depicted in Figure 1 can be applied to business actitivies.

3.1 The ISM as a Timetabling Instrument

The construction of an ISM for timetabling was begun several years ago, but it is only now being developed with a view to serious application. Figure 2 is a screenshot that shows the ISM in its present stage of development. The information it displays is associated with timetabling the oral presentations for final-year project students at Warwick. This involves scheduling about 120 students, each with a supervisor, assessor and moderator, for half hour sessions between 9am and 5pm from Monday to Friday. The timetabler has some discretion over the choice of second assessors and moderators, subject to their areas of competence, and attempts to balance the staff workload. A brief account of some of the features of this application for ISMs will be given here - for more details, see [BWM00].

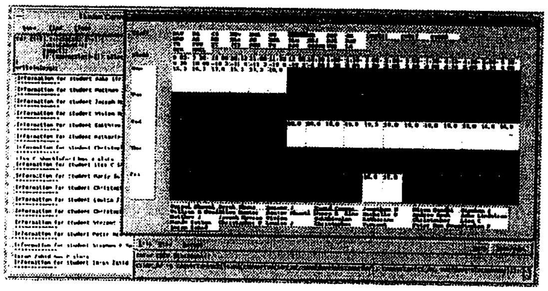

FIGURE 2. An ISM as a Timetabling Instrument

The timetable ISM is best viewed as a form of timetabling instrument to be used to support semi-automated timetabling activity. Its primary role is to assist the manual timetabler in recording and accessing the observables that are of crucial interest in developing the timetable. These include, for instance, the declared and current availability of staff, students, and rooms, the suitability of staff to examine projects, and any problematic consequences of a particular partial or completed timetable, such as instances of double booking or failure to schedule. More significantly, our timetabling instrument is open-ended in the sense that it is - in principle - straightforward to augment the range of observables being monitored, or to reconfigure the way in which they are displayed, without undermining its current state. (That is to say, the semantic relation is respected even when new definitions are introduced in order to extend the instrument's capabilities.)

The timetable instrument was constructed by combining several simpler prototype instruments, each specified by a definitive script together with several user-defined operators to be used on the right-hand side of definitions, and a few associated automatic agents. One component of the instrument was an ISM that captured the way in which the staff scheduling depended upon the timetabling of students and allocation of examiners, for instance. The fact of maintaining such dependencies does not of itself distinguish an ISM from a conventional timetabling tool, but the manner of its construction is significant. It provides the flexibility needed to extend the capabilities of the instrument, and to accommodate singular features of the timetabling situation without reinitialising the ISM. For instance, new definitions can be entered in order to reconfigure the display; to adapt existing components of the display for alternative purposes; to take account of the fact that a student has to use a particular room, or that the room will be then be unavailable for the slot immediately after the student's presentation. An example of adaptation of this kind is illustrated in Figure 2, where the existence of a jointly supervised student is being handled by introducing a spurious member of staff CSSGM, whose availability is dependent upon the availability of CS and SGM.

As discussed in more detail in [BWM00], the phases in the development of the timetabling instrument are similar to those that are involved in developing a more traditional instrument. There is an initial assembly phase, where the component parts, individually tested on artificial data sets, are combined to create the first prototype. This prototype is then tested on reasonably well-understood data generated from an old timetable and its accompanying documentation. There is initially confusion about whether errors should be attributed to the old data, to faults in the instrument or to user error. Whenever there are problems of this nature, the semantic relation is tested through experimental interaction until the source of inconsistency has been identified, and the appropriate corrections and refinements are made on-the-fly. Once such problems have been resolved, the instrument can be applied in a manual timetabling mode, then in semi-automated or fully automated mode. Since the merits of the instrument are particularly relevant to timetabling activity in which a high degree of human interpretation and intervention is involved, the emphasis is on semi-automated activities, where there is an intimate relationship between human and automated contributions.

Providing an appropriate interface for the timetabling instrument is challenging, as the messy interface in Figure 2 may suggest. Unless the development of the ISM is to be used to derive the specification for a conventional timetabling program, it is inappropriate to provide an interface that supports a fixed functionality. To make the best use of the timetabling instrument is to exploit its potential for extension in ways that are opportunistic in character rather than preconceived. In certain respects, the role that pencil and paper can play in manual timetabling is the most helpful parallell here. A particular application for which our instrument is perhaps ideally suited is that of timetabling on-line examinations involving participants on the Internet who are distributed across time zones. In this setting, a distributed version of the timetabling instrument can be used in which the synchronisation of examiners involves the simultaneous use of several different interpretations of their declared availability depending upon the zone in which they are based.

3.2 ISMs in Analysis and Development

Constructing ISMs is potentially a useful way to gain insight into business processes. As discussed in section 2.3, the principal role of the ISM is to help the modeller to connect two accounts of a process: as an abstract pattern of state changes, and as situated interaction amongst agents. There is no methodology that guides this use of ISMs; the model-building activity has a creative open-ended quality and is informed in unpredictable ways by both abstract and situated knowledge. In this respect, it resembles the work of the experimental scientist [Goo90] and the engineering designer [Pug91], who draw simultaneously on existing abstract theories and processes and on practical experience of phenomena and physical devices. Two illustrative case studies will be briefly discussed here.

3.2.1 An ISM for railway operation

Figure 3 shows an ISM that was constructed by P-H Sun to study the circumstances surrounding a historic railway accident [Sun98]. The ISM is distributed over several workstations in such a way that the role of each of the human actors in the accident (two signalmen and three drivers) is represented. The abstract knowledge that informs the model draws on descriptions of the protocols that were followed by signalmen and drivers, and documentation of the operating characteristics of the physical components. The actual interactions of the personnel reflected many other aspects of their real-world situation, including intelligence about the train locations and status that could be obtained or inferred from direct observation, and matters of judgement in which personal experience, skill and memory played a key part. The ISM gives only a very limited impression of many of these factors, but allows the interactions to be studied from the personal perspectives of the agents, with regard to the basic perception of state that could be guaranteed to each. For instance, the display for signalman Killick reflects the fact that he could see trains approaching the tunnel, could observe movements of the telegraph needle, and could hear the alarm sounding when the mechanism to reset the signal failed.

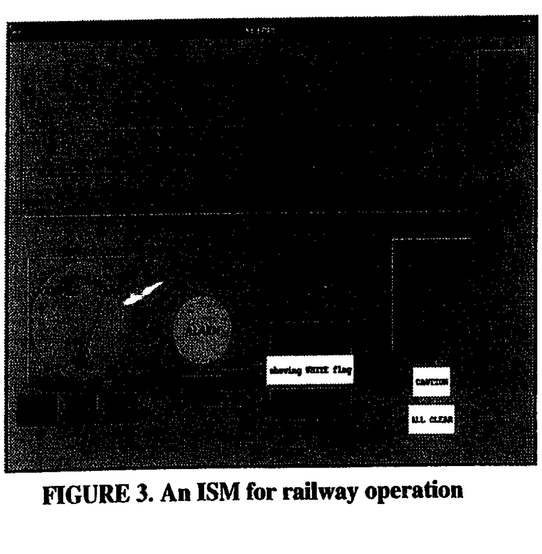

FIGURE 3. An ISM for railway operation

Use of the ISM has proved to be a powerful way to infer elusive information concerning the personal experience of the individuals from the generally well-documented and reliable information about the circumstances of the railway accident. It has not been necessary to embellish the models of state in order for this to happen. Insight has been acquired through becoming familiar with standard patterns of interaction, and through supplying richer and more subtle interpretations of what is being observed in the ISM. The most important ingredient in this activity is the imagination of the human actors engaged in the role-play. Patterns of interaction can indicate the frequency with which trains arrived at the tunnel, the speed at which they travelled, and how these activities synchronised with those of human agents. In order to assess the significance of the time it took Killick to reset the signal (a cumbersome operation involving the winding of a cable), there is no need to simulate the resetting mechanism - it is enough to simply delay this interaction. Matters of interpretation can compensate for other respects in which the iconic representations over-simplify perception of state. For instance, the current status of the signal is registered on Killick's display, though it is unlikely that he could observe this directly. An appropriate interpretation for this icon is that Killick has some knowledge of the state of the signal through inference - Killick will assume that it is set to All Clear when the alarm sounds, and that it is set to Caution after he has performed the resetting routine. In activities of this nature, the imagination and experience of the human actor is being used to give deeper insight into aspects of Killick's own experience that elude formal representation.

3.2.2 An ISM for warehouse management

Figure 4 depicts an ISM that is being developed by Y-C Chen in order to apply similar principles to analysing the business processes that operate in a warehouse application (cf [SCR99]). The principal motivation for such analysis is to gain insight into what aspects of such a process could be re-engineered, and how the requirements for the warehouse could be best met through automation. Role-play in the warehouse ISM has many characteristics in common with the railway accident animation, and serves a similar function in highlighting the way in which agency and observation must be effected so as to achieve an intended result. A significant difference is that the circumstances of the accident are known to have occurred, and can be related to protocols that had already been put in place. In re-engineering the warehouse, in contrast, there is no prior guarantee that an abstract pattern of interactions can be realised effectively in practice, nor is the framework of observation within which each human participant operates yet appropriately circumscribed. For instance, it is evident that the flow of information about the status of warehouse items is closely connected with actual observation and movement of the items themselves. The responsibility for monitoring this real-world state has to be apportioned to the participants, and depends crucially upon aspects of their situation and role that are not formally represented in the abstract business process. The management skills and efficiency of the workmen, the provisions made for alerting them to significant events, and the layout of the warehouse itself will all constrain the extent to which particular participants can monitor the arrival and departure of lorries, check the location of items, or meet specific scheduling demands for collection and delivery.

The use of ISMs in process identification differs from orthodox approaches to re-engineering in the emphasis it places upon distilling processes from the situation in which they are to be enacted. Establishing and maintaining the semantic relation between the ISM and its external referent is associated with first developing effective explanations for activities in terms of actual interactions amongst agents, then seeking to organise these into patterns that are reproducible and reliable. Processes that can be realised in this fashion are more readily adapted both to exceptional singular conditions and permanent changes in situation. Experimental revision and refinement of the semantic relation associated with the ISM can often reflect changes in the real-world situation that it is difficult or impossible to accommodate in a formal process model. The more problematic issue in using an ISM is identifying the appropriate environment in which to conduct observation and experiment.

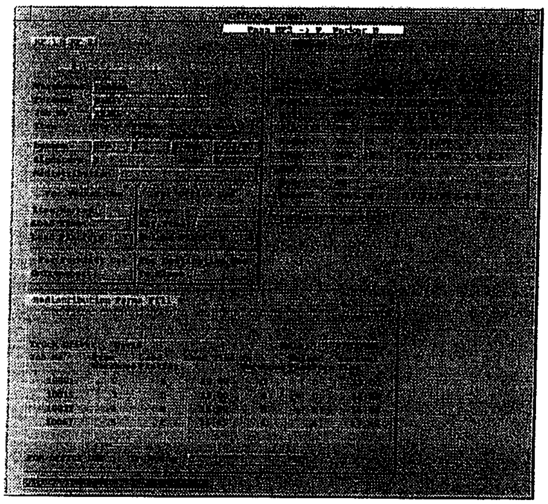

FIGURE 4. An ISM for warehouse management

The ISM depicted in Figure 4 has been constructed by imagining the manual processes that might surround the warehouse operation. The modelling is based around a skeletal pattern of information exchange between warehouse personnel that is directly motivated by the characteristic functions of receiving, storing and retrieving items from the warehouse. In the ISM, the completion and delivery of paper forms is the metaphor for information exchange. Though the technology for such warehouse operation may be obsolete, it leads to an ISM that is well-suited as a basis for further exploration and elaboration. Much of the information recorded on forms relates directly to essential situated actions and observables that must be represented in some form in the business process, however it is re-engineered. For instance, it is apparent that each new instance of a form originates with a real-world event, such as the arrival of an item relocation request, and that the subsequent entries on copies of the form are in effect witnessing to vital observation and action on the part of the associated human agent, such as the movement of an item from a location in the warehouse to a platform preparatory to collection. The use of forms also reflects significant and essential features of a satisfactory business process. These include considerations such as the timeliness of action, the impossibility of revoking actions after commitment, and the need to be able to trace and authenticate procedures and allocate responsibility.

At its present stage of development, the warehouse ISM can be used to enact the form-based transactions that accompany the relocation of specified items from one warehouse to another. The protocols to be followed represent a putative business process that in some respects resembles a use case in the sense of Jacobson [JCJ92]. Whilst the process of form-filling is itself routine, playing the roles of the various warehouse personnel does exercise the imagination in ways similar to those involved in the railway accident scenario. For instance, the point at which a forklift operator sends a form to the office to certify that a task has been completed has to be synchronised with complementary and independent observation of the world. Over and above this, there is a need to monitor the effectiveness of the business process with respect to traceability and robustness in the face of unpredictable external events, such as the late arrival of a lorry, or lazy or deceitful behaviour on the part of participants. The purpose of the ISM is to enable this blending of abstracted and situated views of the business activity (cf. [Tur96]).

A more detailed account of the potential role that the warehouse ISM can have in system development is given in [CR00]. There are a number of respects in which the open-ended modelling activity depicted in Figure 1 can contribute to this development, though no systematic method can be prescribed. All this activity stems from the exploration of the semantic relation between an ISM for warehouse operation and its projected embodiment in real-world practices. It evolves through experimental scenarios freely associated with a variety of referents and foci of attention. The initial emphasis is on experimental interactions that can disclose reliable patterns of state-change in the business situation. At first, these interactions are carried out solely at the discretion of the modeller, with a view to identifying the agency required of each participant and automated component. Once relevant user activities can be construed in terms of plausible interactions between human and automatic agents, experimentation can be directed towards specific issues concerning system requirements. This activity exploits the ISM in a situated problem-oriented requirements engineering framework, as discussed in detail in [Sun99]. Other experimental interaction with the ISM relates to the construction and validation of programs and physical devices to realise the stimulus-response patterns that have been conceived. Business process specification, software implementation and engineering design all feature in this activity, which affects the semantic relation through changes both to the referent and to the ISM.

3.3 Strategic Decision Support Systems

Computers have been used to support business processes within an organisation for more than four decades. The computer broadly provides support for two major activities: collection and management of data and analysis of data. Whilst data collection and management benefit directly from advances in technology, the analysis of data relies more upon the degree of integration between human and computer activities. The main benefits of the use of ISMs may be seen in connection with the latter activity. This is because the scope for human intervention has a key impact on the effectiveness of human-computer co-operation. As the timetabling instrument illustrates, at any particular moment in time it is helpful to be able to combine the qualities of both human and computer agents. The computer compensates for human limitations in respect of speed, accuracy and memory capacity for holding and processing data; the human mind can compensate for the computer's inability to think creatively, to learn from experience, to interact freely with its environment and to discriminate among choices.

In applying the EM approach to business practice, and in particular to decision support, the focus is mainly on human-computer co-operation in data analysis. The development of EM models demands human intervention throughout the whole activity. EM models can not only include an explicit representation of the propositional knowledge of the domain expert or modeller, but can also reflect their tacit knowledge. Experience and skill in business practice are examples of tacit knowledge of the kind that influences the performance of business personnel. An experienced person holds such tacit knowledge to a greater degree than a junior person. This is one reason why including such expertise in computer support systems can benefit the organisation as a whole.

In [Kee87], Keen refers to the merits of "systematic prototyping and the ability to make rapid progress in getting something up and running without requiring the decision maker to provide explicit information - or even to consciously understand the problem and his or her decision making process." In Keen's view, "this is very different from AI knowledge engineering and may help knowledge engineers to move ahead in the messy world of management, where tasks are ambiguous or shifting and rules hard to elicit". The use of ISMs accords well with both Keen's characterisation of the management task and his recognition of the need for an alternative tool to support the problem solving or decision making process. Conventional computer support for problem solving is based largely on mathematical and logical models that are well-suited to pure scientific problems in a fixed context. The vagueness and highly situated nature of social science problems requires a different kind of computer support.

In constructing an ISM, the attention given to observation, dependency and agency is well-suited to the situated nature of business problem solving activities. The different quality of interaction in EM and the cognitive support it affords reinforce the suitability of the EM environment as a platform for business system decision making. For example, in making a strategic decision where the alternatives are of different kinds [Sut98], such as whether to enter a new market or to launch a new product, both quantitative and qualitative analyses are involved. In making such decisions, standard quantitative business analyses have to be complemented to a high degree by qualitative analysis, where judgement is based on a person's past experience and their expertise in interpreting and dealing with different sorts of business situation.

In the 1960s, Simon [Sim60] identified two ways to overcome the limitations of traditional decision making methods. The first is to "discover how to increase substantially the problem-solving capabilities of humans in nonprogrammed situations". The second is to "discover how to use computers to aid humans in problem solving without first reducing the problems to mathematical or numerical form". The EM approach in general adopts the latter stance. In particular, identifying observables, dependencies and agency seems to accord well with the way in which humans informally make sense of things, and lead to a more practical method of constructing computer support systems.

The Restaurant Management Model (discussed in detail in [RRR00]) illustrates some of the ways in which the EM environment may be able to give computer support to strategic decision making. Strategic decisions are identified by Simon [Sim60] as 'nonprogrammed decisions', and relate to managerial decision making activities at the middle and top levels in the organisation structure. According to Simon, such activities are not amenable to mathematical treatment.

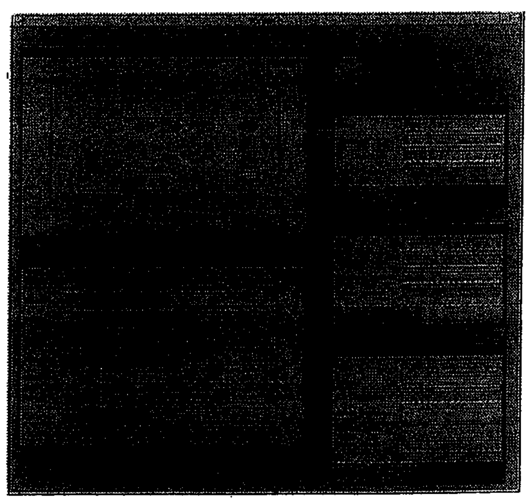

FIGURE 5. An ISM for Decision Support

Figure 5 depicts an ISM for Restaurant Management developed by C Roe. From the outset, the development reflects the way in which the modeller makes sense of the problem domain. As in developing the timetabling ISM, there are several components to the ISM, but in this case their distinct character and significance is more pronounced. A manager may consider the matter of booking and timetabling, and think about such issues in the abstract or in relation to the physical seating arrangements and demands on staff. Their concern may be for specific arrangements pertaining to a single evening, or to trends and the possible longer term implications of changes in strategy for accepting bookings or plans for refurbishment. The openness of the ISM can be exploited in combining observables that relate to each of these different perspectives, and in giving qualitative expression to issues that are impossible to address in purely quantitative terms. The floor plan in Figure 5, and the associated animation of table occupancy as projected from current bookings, is a simple illustration of qualitative feedback. The ISM could be enhanced to include more realistic visualisation, based on a 3-dimensional model, in which it is possible to explore the aesthetic effects of adjusting the lighting, or changing the furnishings.

The family of possible observables that may be relevant to strategic decision support is evidently unbounded, and can in no way be preconceived. In principle, the quality of an ISM can be refined so as to reflect any particular direction to which the decision maker's concern and imagination turns. Though at present the extension of an ISM is an activity that requires the active involvement of an experienced modeller, and can sometimes be obstructed by limitations of the tools, the continuity of the semantic relation is generally well-respected. Conceptually, the evolution of the ISM proceeds incrementally, and at each step new observables, dependencies and agency are introduced as unobtrusively as they enter our everyday experience. This is the case at any rate whilst new experience is consistent with the way in which previous experience has been construed.

A special feature of strategic decision support is the need to take account of many viewpoints, and the potentially conflicting judgements associated with *multicriteria decisions* [Kee87]. In restaurant management, such conflicts arise between the perspectives of the customer, the proprietor and the staff responsible for catering and service. There may also be a need for different views of data according to whether the perspective is specific to a single occasion, or refers to patterns over a period of time. As discussed in [RRR00], there is scope to address these problems through the use of multi-agent distributed ISMs (as illustrated in the ISM for the Railway Operation in Figure 3), and through the integration of components associated with different modes of analysis and observation. For instance, as explained in [RRR00], the ISM in Figure 5 can be run in direct association with a tool that allows patterns in data collections to be visualised and interactively explored.

4.0 Business Computing Paradigms

The business applications of ISMs described above represent a radical shift in perspective on computer use. This section examines this shift first with reference to the history of business computing, then with a view to current and potential future developments.

4.1 Methods, Tools and Users

There are intimate historical links between business processes and computing. Some precedents for the computer program are to be found in the methodical procedures used for calculation and book-keeping in earlier times. An important aspect of the large-scale administrative activities, such as insurance or census processing, that were formerly carried out by teams of people was the way in which they integrated what we recognise as activity characteristic of human sensitivity and intelligence with automata-like behaviour. Despite the enormous social and technological developments of the 20th century, the characteristics of the pre-computing era remain highly influential in current business and computing practice. The foundations for current approaches to processing in business and computing were established in a culture that did not have to address the modern challenges of matching human and automated activities. Characteristic of information processing in such environments was passive storage of information, oblivious and optimised processes and computations, carefully structured and phased activities, and administration through organised and systematic use of tools.

The dominant concepts applied in both business and computing cultures today are the legacy of earlier encounters between people and the automata. They frame human-computer interaction in terms of three interdependent abstractions: *methods*, *tools* and *users*.

Methods: Methods are systematic procedures for changing state and achieving specified objectives. They involve preconceived patterns of interaction and engagement with tools. In computer science, they are associated with computer programs and software development methods. Methods are ways of formulating action that follows a pre-specified path taking account of situations encountered in pre-planned ways.

Tools: Tools are machine-like artefacts customised for a particular use. Tools are invoked by a human user, and interact with their environment in ways that follow prespecified patterns and are to be interpreted using preconceived conventions. In computer science, tools are associated with task-specific computer programs or packages. Tools exhibit reliable responses and behaviours.

Users: Users are defined in relation to tools. They are motivated by a particular goal or task to be performed. Users expect a tool to be reliable, convenient and easy to use, to relieve them of drudgery, and increase productivity in achieving their goals.

Tools operate in the framework set out in Figure 6. In this figure, the left-hand side depicts the recipes for action that are associated with the tool, and the right-hand side a family of interactions with the external world that is reliable and reproducible. Human agency may be involved in the activities represented on both sides. Executing the recipes on the left-hand side demands skill and knowledge in the use of the tool. The user is typically engaged in complementary activity in the external world. There are well-established protocols that link interactions with the tool and interactions with the world.

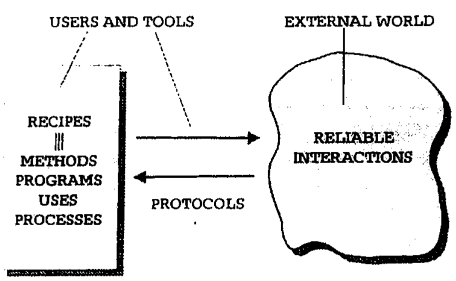

FIGURE 6. The Method-Tool-User Framework

The method-tool-user agenda is suggested by the classical modes of interaction between human and machine. It is associated with a concept of the machine as interacting with its environment in ways that are precisely specified prior to use and strictly controlled in use. This is a paradigm for semi-automated activity that is well-suited to devices like calculators or photocopiers that engage with the external world in a discrete batch-like mode of operation. Whilst the calculator is executing it is oblivious to the state of the external world, and has no autonomous power to affect its environment, at any rate in relation to its intended use. It is for the user to initiate activity on both sides of Figure 6: to invoke the tool, and to take corresponding action in the external world. Though the executing photocopier entails much more complicated interaction with the external world - moving paper, processing and printing images - all this activity takes place according to established protocols that by and large guarantee an entirely predictable outcome. In this respect, its use is also well-represented by Figure 6.

The method-tool-user paradigm has been a powerful influence both in thinking about business processes and computation. Business processes are conceived with the framework of Figure 6 in mind. Reliable patterns of experience are identified; tools and protocols for interaction between tools, users and their environment are designed to exploit these patterns to achieve specific goals. Business process modelling accounts for these interactions in terms of interfaces between human and automated activities that are strictly specified and implemented. In the interests of efficiency, great emphasis is given to guaranteeing the reliability of the environment and optimising interactions to serve their intended purpose. This is an incentive to limit the autonomous control over their environment and the responsiveness to their environment required of both tools and human agents.

The method-tool-user paradigm promotes a particular view of the computer as a general-purpose tool. The computer is primarily regarded as able to play the role of many pre-existing tools, such as the mechanical calculator, the filing cabinet, and the paper spreadsheet. This perspective on its generality has also been promoted by the prominent place of batch programming in the early history of computing. In the classical abstract input-output view of computation, the computer - courtesy of a program - can perform any particular function. During much of its short history, business computing has tended to reinforce the role of the computer as a tool for calculation and storage whose impact on its environment is always mediated through organised human agency.

The method-tool-user culture currently faces challenges from both the computational and the business perspectives. The computational frameworks for managing both ephemeral and persistent data that are best understood do not seem to be well-suited to modern computing needs [Atk89, DD98, Sto90]. Computing practice increasingly embraces reactive systems, in which computer-based components respond and act directly upon their environment, but neither the traditional theory of computation nor the methods of software engineering offer adequate support for their development [Bro95, Har92]. Relational theory provides the most plausible mathematical account of databases, but supports a view of data that is too passive to encompass many practical developments in database use. These include matters of data presentation and manipulation, the treatment of rules, triggers and live feeds of data, and the combination of functional dependency and agency that is to be found in spreadsheet interfaces [DD98].

The practical impact of pervasive computing and communication on business has operated in parallel to challenge classical views of the business process. More widely devolved information processing, new technologies and global communication all have a potentially radical impact on business organisation. In the modern business environment it has become much more difficult to anticipate behaviours and formulate reliable methods to achieve goals. The organisational principles that are most effective when managing people cooperating in human and automata-like roles are no longer sufficient. The method-tool-user approach does not apply where it is difficult to impose control or patterns, suppress autonomy or circumscribe state. What is more, the optimisation that is most appropriately invoked in the setting of a stable reliable process is out of place where there is rapid change. On the one hand, it obscures the conceptual framework in which the optimisation operates. On the other, it involves commitments to particular narrow objectives that make change difficult and costly.

4.2 A Paradigm Shift

Contemporary technology and practice is changing the balance between the human and the automatic in ways that will radically affect the character of computer-supported business activities. The trend towards ever faster processing and larger storage capacity is an aspect of this change, but its most significant impact is upon the relationship between the computer and its environment. The computer need no longer play so passive a role in human-computer activities - in some circumstances, it no longer requires the human user as an intermediary to react to or act upon the state of the external world. Through sensors and actuators, devices can now directly reflect the state of their environment, and directly contribute to this state. Through virtual realities and the possibility of linking interfaces directly to the eye and brain, the computer can engage with human agents in ways that appeal directly to their experience rather than their reason. This elevation of the computer to the role of an agent for change introduces quite new problems and dangers. It also offers much greater potential for integrating human and computer activity.

The implications of the computer as an agent cannot be interpreted effectively in the method-tool-user paradigm. The framework for analysing interaction between users, tools and their environment depicted in Figure 6 relies essentially upon presumptions about reliable patterns of experience that are exceptional rather than normal when automatic agency is involved. To address such agency, the focus has to shift from behaviour that can be dictated by global rules to interactions that emerge from local stimulus-response patterns. The significance of this shift is evident even in the most abstract forms of programming. By way of simple illustration, contrast the systematic procedure in bubblesort (whereby adjacent elements in an array are compared and if appropriate exchanged according to a pre-established pattern) with a sorting procedure that involves placing an autonomous agent to take charge of monitoring each adjacent pair of array elements and exchanging them if appropriate. In bubblesort, the procedure is entirely driven by pre-determined protocol - the unique pair of elements that will be compared at each step is known in advance. In the agent-oriented variant, in the absence of any synchronisation protocol or cues for the agent actions, the behaviour is incompletely defined. There is the possibility of conflict and perhaps deadlock, for instance, if the two agents observing the sequence of adjacent values 5,4,3 act simultaneously. In these circumstances, it is not entirely clear how or even whether sorting will be effected.

The applications of ISMs illustrated in this paper are intimately connected with understanding and exploiting stimulus-response patterns. (This is discussed in greater detail with reference to abstract programming in [BRS99], where the use of an ISM in the development of heapsort is described, and in relation to the following account of how projection is involved in agency in [Bey99].) Where human agents are concerned, accounting for interactions in stimulus-response terms directly invokes an experiential perspective. Attention is focussed on how human agents apprehend state and effect state changes in actual and physical rather than abstract and logical terms. Though it is hardly appropriate to speak of the 'experiences' of an automatic agent, it is apparent that our understanding of agency is informed by projecting human experience of interaction onto other agents, whether human or inanimate. For instance, it is natural to consider an automatic camera as observing the external scene and adjusting the aperture and focus accordingly. The principal function of the ISM is to represent interactions that involve other agents in terms that make this projection explicit. To this end, the ISM embodies visible and tangible counterparts for the observables that are presumed to govern the interactions between other agents.

The treatment of observables that mediate interaction between agents is the key distinction between Figure 1 and Figure 6. In Figure 6, there are two presumptions: that patterns of interaction between agents are reliable and that the observables by which these interactions are mediated are comprehensively understood. It is significant that the concept of 'comprehensive understanding' is meaningful only in relation to the method-tool-user perspective. The protocol through which a photocopier, for example, interacts with the external world in Figure 6 references only a limited set of observables, even though the machine can self-evidently engage with the external world in ways outside the scope of its intended use, as when it tears up its input, temporarily blinds the irresponsible user, or catches fire. In Figure 1, no such absolute presumptions about interactions or observables are invoked. In the ISM, as in a spreadsheet, the current state reflects the relationships between observables as they are currently understood. This understanding expresses provisional expectations rather than certain knowledge, and is at all times the subject of confirmation or refutation through experiment. There is unbounded scope for extension and revision of the observables. Expectations about reproducible patterns of state change can be represented in the ISM, but their enaction is always a matter for future experience and ongoing reappraisal.

The distinction between Figure 1 and Figure 6 draws attention to an analysis of agency that is central to understanding emerging information systems. Where there is potential for autonomous action in a complex system, there are two ways in which this can be safely expressed and managed. One approach is to constrain the environment so that the impact of autonomous action is guaranteed to be safe, appropriate and reliable. The other is to give agents richer access to the state of their environment. Whereas in the past the operating environment and the agency associated with automatic devices and user protocols might remain stable or evolve gradually over long periods, this is no longer the case in modern businesses. Figure 6 is the appropriate framework for stable business processes. Figure 1 is the more appropriate framework for contemporary business.

Human capacity to adapt to change is closely linked to understanding. Having good insight into how different agents in a system operate is a prerequisite for adaptation of the system. An ISM is a means to represent the modeller's - in general partial and evolving - knowledge of state and agency in the external world. In using computer technology effectively to enhance the quality and flexibility of business activities, it is helpful where possible to embed the modeller's knowledge of state and agency into automatic devices. Whether this is feasible depends on the physical characteristics and roles of these devices - in particular, whether they can gain timely access to the key observables that determine the state of the external referent. Technology not only broadens the options for fully automating this access, but can also enhance the potential to integrate human and computer activities. As the timetabling instrument illustrates, where human speed of thought and interaction is sufficient to purpose, the use of an ISM is an effective way to integrate human insight with computer management of state and state-transition.

From a business perspective, it is in a narrow sense both cheaper and more efficient to deliver a specific functionality using automatic agents that operate in a constrained environment to which they are as far as possible oblivious. The shift in perspective represented in moving beyond the method-tool-user paradigm has created new business incentives to seek alternative computing solutions, where the emphasis is on integrating devices into their environment in a much richer if less highly optimised manner. Where modern business applications of computing are concerned, integration of this nature is essential both in coping with the dangers of closer coupling of computers to real-world state, and in building in flexibility to adapt to new circumstances. It also relates to other issues that are not motivated solely by narrow business goals and purposes, but by the broader desire to make the tasks of employees and users more creative and satisfying. To this end, the objective is to provide human agents with computer support that can be aligned to their evolving objectives and aspirations (cf. the Idealist Timetabler in [BWM00]). The use of ISMs supplies an appropriate setting for the necessary exploration, invention and experiment, which lies outside the method-tool-user framework.

5.0 Conclusions

This paper has discussed the potential application of ISMs to business. This activity can be interpreted as addressing issues beyond the scope of the established approaches to business modelling and computation, which are based on a method-tool-user paradigm. The use of ISMs is associated with a shift of perspective in which the principal emphasis is placed upon how the interaction in a complex system can be construed in terms of agents and their access to the state of their environment. This can provide the basis for new forms of decision support in business, assist business process re-engineering and enable the construction of computer-based instruments in which human and automated activities are intimately integrated.

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