Cognitive Artefacts for Decision Support

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Abstract

We introduce a novel approach to computer-based modelling which allows the construction of cognitive artefacts with an unusual degree of openness and a potential for close integration with other artefacts and with human processes. Four particular artefacts concerning railway operation, timetabling, restaurant management and warehouse management are described briefly and attention is drawn to those properties concerning knowledge representation and communication which show that the modelling methods used here have a significant contribution to make to the development of more effective decision support systems in a business context.

1 Introduction

In this paper we describe an approach to computer-based modelling which has far-reaching principles and espouses a distinctive paradigm for computation. These principles pervade the methods and tools developed and give rise to the unusual quality of interaction possible with our models and their high degree of flexibility and openness. In section 2 we give an overview of the approach and the kind of cognitive artefacts which we can construct. We make reference in section 3 to four particular artefacts built recently which illustrate different aspects of the main thesis of this paper: that effective decision support systems in a business context require modelling methods which can embrace experiential and qualitative knowledge as well as propositional and quantitative knowledge. Finally the conclusion summarises what has been described and what is different about the approach.

2 Cognitive Artefacts & Empirical Modelling

Cognitive artefacts have been defined by Norman as 'those artificial devices designed to maintain, display, or operate upon information in order to serve a representational function and that affect human cognitive performance' [10]. Thus diagrams made with pencil and paper would be familiar cognitive artefacts. In the work cited Norman gives a classification into four kinds of artefact according to whether it gives a surface or internal representation, and whether it is passive or active (can be operated upon and modified). Typical active artefacts in Norman's sense would therefore be the drawings, texts and simulations that can be built with conventional computer packages, as would the models used by engineers in wave tanks and wind tunnels. Some process of modelling seems to be essential to the notion of a cognitive artefact. Some means of interaction is essential to an active cognitive artefact. The tools used to build computer-based artefacts have to be programmed and conventional programming has been dominated by the problems of managing the translation between human conceptual representations and machine-level representations. One consequence of this is that the interactions possible in a conventionally programmed artefact are - however numerous - likely to be limited and preconceived by the programmer. This may be a major restriction on the faithfulness of the modelling and the value of the artefact for conveying knowledge. This is especially true in modelling human activity systems (such as a business application) where the knowledge needed may be such that it only arises through rich and open-ended kinds of interaction.

The approach to computer modelling which we describe here is one which is based fundamentally on the modeller's own construal of a phenomenon in terms of *observations*, *dependency* and *agency*. The dependencies and agents present are identified through experimental interaction with both the model and its real world referent. Because our approach is based on observation and experiment it came to be called Empirical Modelling (EM). This is now the theme for a substantial research group at the University of Warwick - see the web-site [7] for background and further details. A major motivation for EM is to complement symbolic, or rule-based models (e.g. mathematical or logical models) with models which offer the user experiences of interaction that directly compare with real world experiences (cf. [1]). With the limitations of current interfaces such interactions often need to be mediated by metaphors, such as icons, rather than by a 'realistic' kind of experience.

We often refer to our models as interactive situation models (ISM) drawing attention to the unconstrained interaction possible with the models, and the fact that they have a situated quality in contrast with generic, abstract models typical of mathematical modelling methods. An 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 emerges dynamically through interaction with the model, and through direct comparison with interactions with its referent. The modeller perceives that the state of the ISM accords (or does not) with the state of the referent. This perceived association between model and world the – *semantic relation* – is to be treated as an irreducible feature of human experience. Within the computational framework of EM the state of an ISM is described by a family of definitions, or a 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 which has integrity and identity.

An ISM, especially in the early stages of construction, is a provisional and subjective model with the here-and-now character of a particular situation well known to the modeller. Further observables and dependencies can be added to a model in a completely open-ended fashion, rather like the evolution of a spreadsheet model. These properties of openness and situatedness reduce the sharp separation between model and referent inevitable in a mathematical model and offer the possibility of a user gaining qualitative knowledge of the world through interactive use of the model. In addition, an EM approach enables integration that is important for a business ISM: both formal and informal knowledge are included, analysis and design are intertwined, and interface issues are made integral to the system. We regard these ISMs as examples of powerful cognitive artefacts in something like Norman's sense. But we would put more emphasis on the role of interaction for establishing the faithfulness of an artefact than the "representational function" mentioned by Norman. An ISM relies upon an explicit representation of state that involves the selection of certain observables. But the term representation here should be understood in a broad sense in which we might speak of a painting as a representation. We recognise the inevitable incompleteness of this representation. Each state-as-experienced is more than any representation of it. Figure 1 depicts the semantic relation (the meaning, or possible knowledge content) 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.

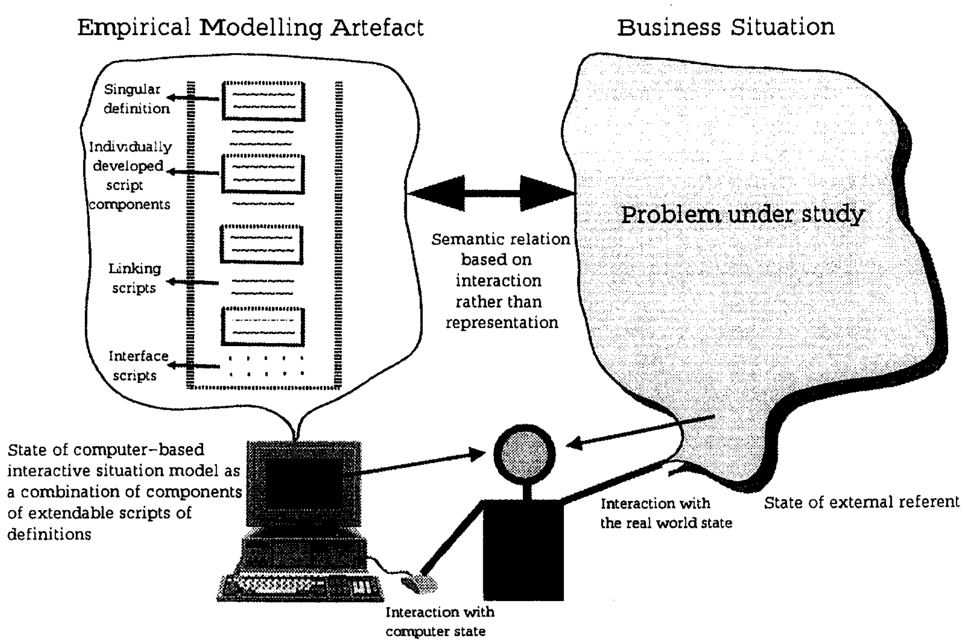

FIGURE 1. Open-ended Modelling with Scripts

3 Cognitive Artefacts for Decision Support

Decision making is a vital part of business practice at every level of management. Sutherland [11] has classified three levels of decision making: operational (e.g. processing sales transactions), tactical (e.g. production planning) and strategic (e.g. corporate strategy) - each one calling for a higher degree of human intervention than the previous one. We have argued in another paper [12] how EM models are particularly appropriate to strategic decision support. While all information systems make essential use of collections of meaningful data we suggest here that decision support calls for the essential use of collections of models. This is not simply for simulation models helping in the final selection process of decision making but also for the identification of problems and design of alternative solutions. After reviewing major theories of decision making and of uncertainty, Fox [6] points out, '[they reveal] a pre-occupation with mathematical interpretations of uncertainty, and a lack of concern for the obvious point that knowledge must be important somewhere'. We suggest that the concept of an ISM, as a particular kind of computer-based cognitive artefact that integrates closely with human participation, is well-suited to giving flexible and effective decision support. Such support will supplement that available from conventional data analysis methods. The principles of EM are close to the way humans operate and our methods can be viewed as a generalisation of spreadsheets. We therefore aspire for our tools to be usable by end-users such as managers although at present our tools are not sufficiently well-developed to allow this in general. Now we present very brief summaries of four current ISMs and point out their contribution to the features required for effective end-user decision support.

3.1 Railway Operation

An ISM constructed by P-H Sun [14] concerned the circumstances surrounding an historic railway accident involving the first use in Britain of a telegraph to control access to a tunnel. The ISM is distributed over several workstations so that the role of each of the human actors in the accident (two signal men and three drivers) is represented. The abstract knowledge that informs the model makes use of the relevant protocols being followed and characteristics of the physical devices. The resulting interactions allow for normal use to be animated and also the accident scenario to be reproduced. The use of the ISM has proved to be a powerful way to infer elusive information concerning the personal experience of the individuals from the documentation about the circumstances of the accident. 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 important ingredient in this activity is the imagination of the human actors engaged in the role-play. The model, exploiting a distributed version of our tools, allows insight into the aspects of the signalmen's experience that could not be captured in any formal description. For managers to gain such insights into the experience of employees in carrying out various work practices would have obvious value for decision support and is not something offered by conventional systems.

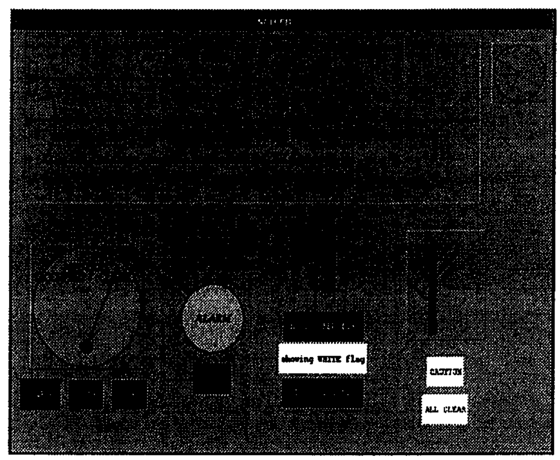

FIGURE 2. An ISM for Railway Operation

3.2 Timetabling

This ISM can be viewed as a form of timetabling instrument to be used to support semi-automated timetabling activity. Our current example is managing the information concerning the scheduling of oral project presentations for about 120 students each with three staff members in a half-hour slot within a given week. Its primary role is to assist the manual timetabler in recording and accessing the relevant observables. These would include the declared and current availability of staff, students and rooms, suitability of staff for a given project, the balance of staff workload, and any problematic consequences of partial allocations such as double booking or failure to schedule. A detailed account of the construction and use of such an instrument is given in [2]. The timetabling instrument is open-ended in the sense that it is – in principle – straightforward to augment the range of variables being monitored, or to reconfigure their display, without undermining its current state. That is, the semantic relation is respected even when new definitions are introduced extending the instrument's capabilities. The major technical challenge here is to give computer support to the mental engagement involved in expert manual timetabling, that is, to exploit the advantages of automation and yet retain the qualities that human interaction brings. Conventional programming for such support falls far short of effective human-computer integration because of the need to circumscribe the application before automation. The evidence of our work with this ISM, and the openness already mentioned, suggests our methods can offer automated support without such circumscription of the domain.

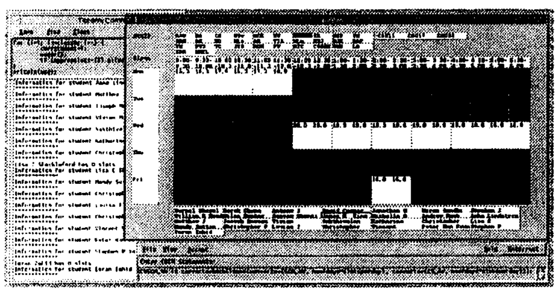

FIGURE 3. An ISM as a Timetabling Instrument

3.3 Restaurant Management

The Restaurant Management model illustrates some of the ways in which an EM environment may give support for strategic decision support. Such decisions were identified by Simon [13] as 'non-programmed' decisions and relate to managerial decision making at the middle and top level of an organisation. Rather than directly supporting strategic decision making this ISM illustrates a number of features essential to such activity, e.g. the capacity to cope with imprecise, qualitative problems, to be amenable to end-user development and allow distributed access to several users. This ISM was developed in a short time (days rather than weeks) by Chris Roe and a detailed account of its construction and use is given in [12]. The user is presented with a floor plan of the restaurant, a block diagram of current bookings and an interface for bookings and cancellations. The expected profile of occupancy for a given evening can be animated to give qualitative feedback to a manager to assist in decision making about bookings. Strategic decision support needs to take account of many viewpoints, and the potentially conflicting judgements associated with *multicriteria decisions* [9]. In restaurant management, such conflicts may arise between the perspectives of customers, the proprietor and the staff. Our ISM can address such problems through the use of distributed ISMs and the integration of components for different modes of analysis and observation.

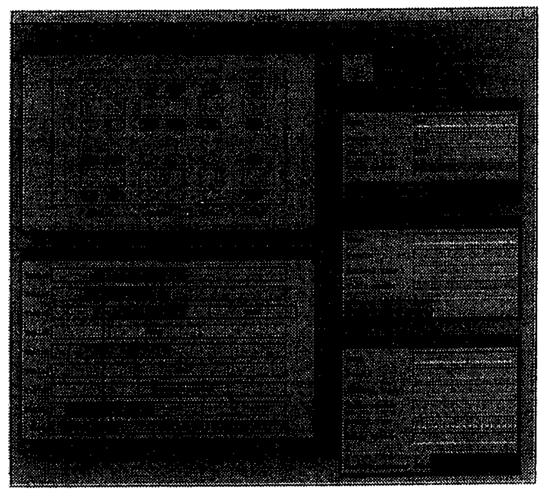

FIGURE 4. An ISM for Restaurant Management

3.4 Warehouse Management

An ISM is currently under development by Y-C Chen in order to apply EM principles to the analysis of business processes involved in the management of warehouses. In particular our focus has been on the process of re-distribution of goods between warehouses (see Figure 5 and further details in the papers [5] and [4]). A major motivation for this modelling is to gain insight into which parts of a process could be re-engineered, and how some of the requirements for all the processes involved might best be met through automation. Role-play by the participants in a distributed version of the ISM gives insight into the agency and observations required for certain changes to occur, as in the railway operation ISM. But in contrast to the railway, where the accident was known to occur, we cannot be sure in advance that some abstract pattern of interactions can be efficiently put into practice. The skills and behaviour of the staff, how they are alerted to significant events, and the layout of the warehouse itself may influence how participants monitor the arrival and departure of lorries, check the location of items, or meet scheduling demands for collection and delivery.

The modelling for this ISM is based on the requirements for re-distribution and the metaphor used for the exchange of necessary information is the completion and delivery of a set of paper forms. Much of the information on the forms relates directly to essential situated actions and observables that must be represented in the business process, however it is re-engineered. The use of an ISM here, in contrast to conventional approaches, emphasises the abstraction of processes from the situation in which they are to occur. Establishing the semantic relation between the ISM and its referent first needs explanations for activities in terms of actual interactions amongst agents, then these need organising into patterns that are reproducible and reliable. Processes that can be derived and made practical in this fashion will be more readily adapted to unusual conditions or permanent changes. The protocols and the requirements to be satisfied are related to a use case 'manual re-distribution between warehouses' described in a work on object oriented development [8]. The authors specify the use case for the computer system to be developed by preconceiving all possible interactions by users of the system. Our ISM has a very different character in being ever open to changes in the requirement and the situation of use. There is no final circumscription of the application and appropriate interactions – only an interface designed with the involvement of participants and open to further evolution by the modeller.

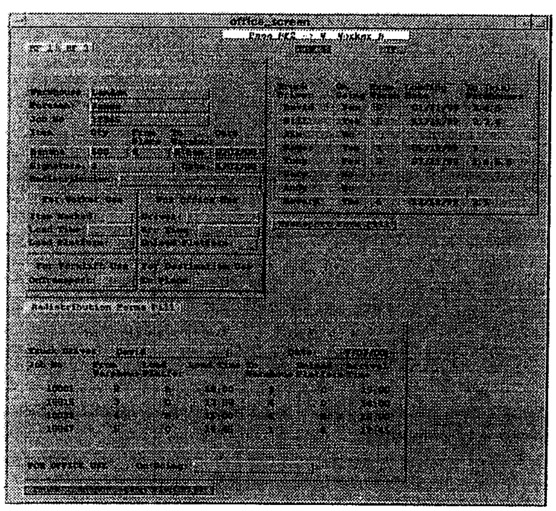

FIGURE 5. An ISM for warehouse management

Experience with this ISM suggests that when more completely developed it could offer decision support at all three levels mentioned above. At the strategic level it could help managers decide on whether to go for a computerised system at all by performing simulations and seeing the impact on administration, efficiency and staffing levels. Having adopted some form of computer-based system the artefact could then be used to help identify problems of where competitors were gaining advantage and possible solutions at a tactical level. For example, there may be scope for customers to be able to make on-line requests for re-distributions, for truck drivers to report progress or delays online via WAP phones etc. Finally, there is clear scope for stakeholders to participate in such an ISM to identify ways of improving the efficiency of processes at a day-to-day operational level.

4 Conclusions

We have described how the introduction of a new paradigm for computer-based modelling, Empirical Modelling, allows the construction of a type of cognitive artefact which we have called an interactive situation model. Brief accounts of four such ISMs have been given together with references for further details. While the functionality of our models at any point in their development can be reproduced by conventional models, we have drawn attention to some fundamental differences of principle in our approach which have important consequences when seeking to integrate human and computer-based support in a turbulent human-centred environment such as the business world. We have emphasised that our approach does not need prior circumscription of a domain to offer useful support and that there are grounds for supposing that end-user development may be more realistic with our methods than those of conventional programming. The examples of ISMs described each illustrate some distinctive aspect of our modelling methods that is important either for sharing knowledge or for decision support – including group and strategic decision support. Space does not permit further technical details of our notations or tools but these are described further in many of the papers cited from our group and from the sources available on the EM web page.

Acknowledgements

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