Interactive Situation Models for Cognitive Aspects of User-Artefact Interaction

Meurig Beynon, Chris Roe, Ashley Ward, and Allan Wong

The Empirical Modelling Research Group, Department of Computer Science,
University of Warwick, Coventry, UK CV4 7AL
`http://www.dcs.warwick.ac.uk/modelling/`

Abstract. Cognitive aspects of human interaction with artefacts is a central concern for Cognitive Technology. Techniques to investigate them will gain greater significance as new products and technologies more closely customised to specific users are introduced. The study of Cognitive Dimensions is a well-established technique that can be used to support and direct empirical investigation of cognitive aspects of artefact use. This paper proposes a complementary technique, based on constructing 'interactive situation models', that applies to the study of specific user-artefact interactions. It interprets the cognitive activities of the user through interrelating situational, explicit, mental and internal aspects of state. The application of this approach in analysing, recording and classifying such activities is illustrated with reference to a simple case study based on modelling the use of an actual digital watch. The paper concludes with a brief discussion of possible connections with Cognitive Dimensions and implications for 'invisible computing'.

1 Introduction

A central concern of Cognitive Technology (CT) is the impact that the use of artefacts can have upon the mind of the user, and its broader implications for users in their social, cultural or administrative context. The study of CT demands analyses and techniques that can take full account of the interplay between human cognition and technological products. As computer-based technology advances, and new modes of human-computer interaction are being developed, cognitive aspects of human-computer interaction acquire ever greater significance.

In current practice in designing and implementing artefacts, the activities that relate most strongly to the agenda of CT are arguably the empirical studies undertaken by interface designers in developing an *information artefact* (IA) [8]. These involve monitoring the way in which potential users interact with an IA, and observing the problems they encounter. In this context, the experimenter is not necessarily explicitly concerned with what goes on in a user's mind, but sees the consequences of common mistakes and misconceptions, and explores practical steps that can be taken to eliminate them through redesign. Such empirical activity is intimately — if not necessarily directly — concerned with both human cognition and technological development.

The informal nature of the testing activity and the nature of the insights that are gained through experiments with users pose challenges for representation. The intuitions of gifted and experienced designers typically play a crucial role. By drawing on their experience, good designers become astute at interpreting user difficulties and relating them to problems in the design of the artefact and its interface. The tacit acquisition and application of knowledge may serve the purpose in some design contexts, but requires skill and judgement that is not easy to develop and to share. This motivates the search for supporting techniques and frameworks that can make the analysis of cognitive issues in artefact and interface design more systematic, and results of the analysis more accessible for recording, exploring and communicating.

The study of cognitive dimensions (CDs), as introduced by Thomas Green in [7], is one approach to this issue. CDs provide a generic framework to guide the empirical study of IAs. This involves the identification of generic activities that are represented in user interaction with IAs, and the investigation of the cognitive demands made on the user in carrying them out. The study of CDs can inform the design of IAs, but it also serves a broader function of framing the agenda for discussion of their qualities and deficiencies from the perspective of a typical user. Knowledge about trade-offs between dimensions, for instance, is the same kind of knowledge that an experienced designer draws on when evaluating a redesign.

Human interaction with information artefacts can be conceived and viewed from two perspectives. In closed user-artefact interaction, the roles of the human user and responses of the artefact are enacted within a stable well-established context, where all instances of use are precisely identified and characterised in the user manual. The appropriate model for such use of the information artefact is as depicted in Figure 1. The archetype for closed user-artefact interaction is provided by standard use of a device such as a digital watch that has been specifically designed to perform particular functions in appropriate situations according to preconceived conventions for interpretation.

The concept of closed user-artefact interaction implicitly imposes a stereotype upon the user. Modern developments in technology motivate a different perspective on human interaction with artefacts. As Cooper points out in [5], sophisticated computer-based artefacts take on the characteristics of the computer. This means that their behaviour can be customised, reprogrammed and reinterpreted by the user; their responses can be adapted to the user and the situation. Because individual users can directly shape the artefact, their personal experience, their competence, their knowledge and conception of the intended function of the artefact become crucially significant. Even the concept of specific uses of the artefact may be suspect, and the role of the person involved in the interaction is more aptly characterised as *user-designer* rather than mere user. Both use and experiment then feature in the interaction with the artefact and

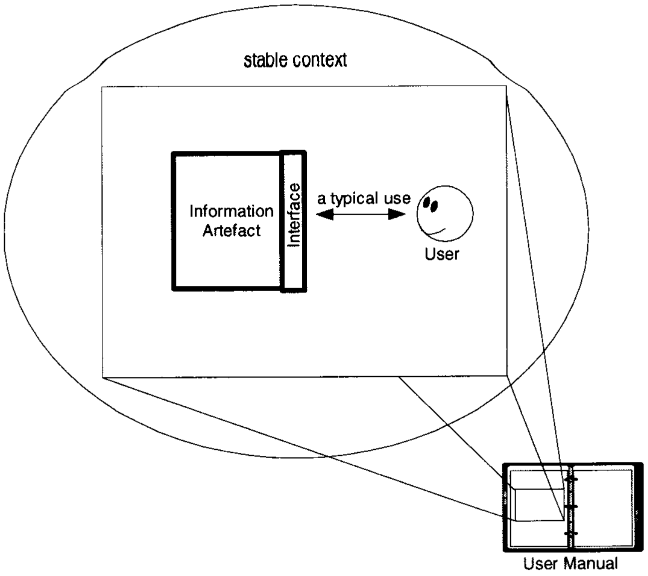


Fig. 1. Closed User-Artefact Interaction

the manner in which these are to be interpreted need not be fixed in advance but can emerge from experience in the context.

This open human-artefact interaction perspective is more in tune with a CT perspective. The use of an artefact, rather than being subject to a preconceived specification suited to a 'generic' user, is essentially hard to prescribe. It migrates in ways that cannot be anticipated, evolving with the users understanding and familiarity, and as the surrounding social and administrative context is adapted. The impact of this migration can be so radical as to embrace serendipitous patterns of interaction with the artefact that were originally uninterpreted.

This paper investigates a modelling technique for studying cognitive aspects of the use of an information artefact. This involves representing interaction with an information artefact by devising an interactive situation model (ISM) using principles and tools that have been developed by the Empirical Modelling (EM) research group at Warwick [14]. Our aim is to show that modelling with ISMs supplies a useful framework in which to examine cognitive aspects of user-artefact interaction, both open and closed.

2 Aspects of State in User-Artefact Interaction

The term 'information artefact' was introduced by Green and Blackwell in their study of CDs [8]. From the perspective of this paper, an IA is viewed as a construction whose state can be consulted or manipulated in such a way as to

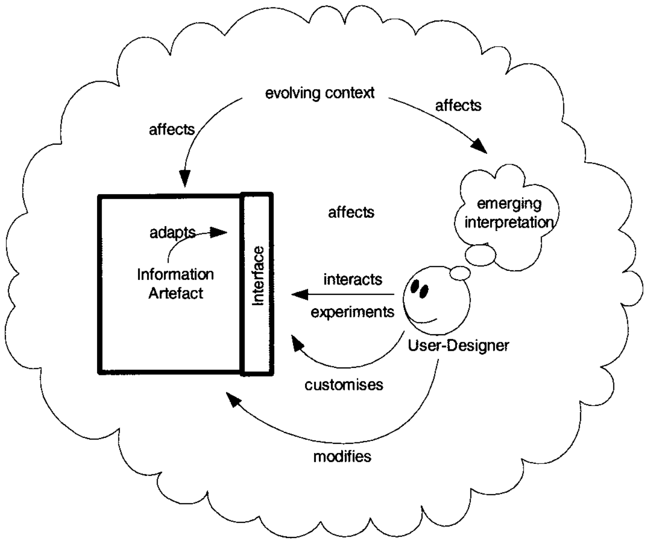


Fig. 2. Open User-Artefact Interaction

reflect the state of an external referent. Both non-interactive and interactive IAs fall within the scope of this definition, the distinction between these two kinds of artefact stemming from their capacity to undergo changes of state. For instance, a map is a non-interactive artefact whose referent is the geography of a region — though the map of itself undergoes no change of state, a state change is invoked when the map user points to a map location so as to refer to an external feature. In contrast, a digital watch — the primary information artefact used for illustrative purposes in this paper — is interactive, and makes state transitions in response to user actions.

For our purposes, the salient issues concerning an information artefact are that its use is situated, that it is perceived as having a state that can be to some degree changed in a deterministic manner by its user and that its function is prescribed by an abstract concept of 'appropriate use'. Appropriate use here refers to a norm of intended use, whereby the artefact serves to support particular activities, according to some standard conventions for interpretation. For a digital watch, the intended uses might include recording and potentially displaying the current time, fulfilling an alarm function, and serving as a stopwatch. In considering the use of an artefact, it is important to bear in mind that the user cannot necessarily recognise when interaction with the artefact conforms to this norm. For instance, to make appropriate use of the digital watch for telling the time you must know whether your watch is slow, whether it is currently British summer time, and which time zone applies to your current location.

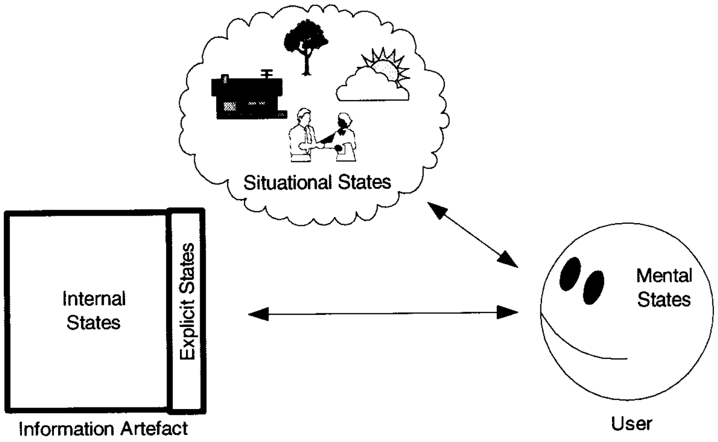


Fig. 3. SEMI Aspects of State in User-Artefact Interaction

Many aspects of state are relevant to the appropriate use of an IA. These aspects are typically specific to each instance of use, and have to be simultaneously apprehended by the user. These will be classified as follows:

- explicit: the visible (or otherwise directly discernible) state of the artefact;
- situational: knowledge of the real-world context to which the artefact refers;
- mental: the state that we project upon the artefact when interpreting its current state and consulting expectations about its possible next state.

Aspects of the internal state of the artefact, of which the user is not in general aware, may also be relevant — these are certainly significant when the relationship between the artefact and its referent is perceived as inconsistent by the user. Such a perception may stem either from many sources, such as a misconception on the part of the user, a singular condition in the external situation, or a malfunction of the artefact.

These aspects of state can be elaborated with reference to a digital watch. *Explicit* state is what I can see merely by looking at the watch (simplified here by discounting other sensory channels, such as sounds the watch might emit, but without loss of generality). For instance, by looking at the watch display it may be impossible to tell whether it is in the 'display current time' mode, or shows the time at which the alarm is set. *Situational* aspects of state supply the norm for digital watch use. In appropriate use of the digital watch, knowing the actual time is significant. Knowing how to use the stopwatch function means having a fairly subtle understanding of external activities: such as 'running a race', 'lap time' etc. *Mental* state references complementary knowledge about state that has to be carried in the user's head to make sense of its behaviour. Though I may not be able to tell by looking at the watch whether it is in stopwatch mode or the 'display current time' mode, I may have reliable knowledge about this through recalling what abstract state transitions have been performed on the watch. For instance, I may know that it was displaying the current time, that I then pressed button X twice, and that this takes me into the stopwatch mode. The *internal* state is what someone testing or repairing my digital watch might consult — using special instruments to monitor the state of the digital circuitry etc whilst operating the buttons. The internal state of the watch is not usually accessible to the user, nor of concern to the user in so far as the watch operates reliably.

Activities that help to identify these aspects of state include:

- explicit state: take a snapshot, and show it to a third party who has not been engaged in interaction with the artefact;
- situational state: contrast playing with a digital watch that has already been set up for use and playing with a new watch, or contrast observing the watch in active use and experimenting with it in isolation;
- mental state: consider the knowledge of state that the user necessarily has to have to use the watch appropriately, but cannot be inferred from a snapshot of the current display.

The way in which these various aspects of state interact is highly complex. The context in which appropriate use of the artefact is set is teeming with empirically established assumptions. In general, the user is juggling with the relationships between all these aspects of state even as they try to put the watch to standard use. It can be difficult for the user to confirm that what is observed about the state of the artefact, what is simultaneously observed about the state of the world, what is inferred from knowledge of interaction with the artefact and what is presumed about integrity of the artefact and the user are all 'consistent'. Judging the consistency of such relationships between observations, presumptions and recollections of state is a dynamic empirical matter.

The cognitive demands of using an information artefact are shaped by the way in which the situational, explicit, mental and internal (SEMI) aspects of state are correlated in the mind of the user. The precise characteristics of this correlation differ from user to user, and will need to be determined by an empirical study of each individual user. Taken as a whole, the design of the IA is informed by a particular correlation between the SEMI aspects of state that corresponds to appropriate use of the artefact by a fully informed and committed user. Such a user is primed — for instance, by a user manual — about the idealised model of use with reference to each of these aspects of state. An account of idealised use of a digital watch will refer to situational state (e.g. "determine the current time"), explicit state (e.g. "when the alarm symbol is visible"), mental state (e.g. "recall that the watch can be in several different modes") and internal state (e.g. "when the display disappears, the battery needs replacing"), and to relationships between all four aspects.

The effective use of an information artefact requires experience of the artefact as well as familiarity with the user manual. Following standard practice in EM [14], the requisite experience can be the subject of an appropriately constructed ISM. Such an ISM aims to represent, in a manner that is both provisional and extensible, the way in which the SEMI aspects of state interact in use of the artefact. Because of the essential openness of the ISM, the ISM is at no point deemed to be a complete or perfect model, but can be readily refined and adapted to reflect different scenarios of use. In particular, an ISM that represents the designer's canonical model of use can serve as a 'seed' ISM from which a host of variants can be developed as needed. For instance, there will be variants to correspond to users with partial knowledge of the functions of the IA, perhaps with misconceptions about the correlation between SEMI aspects of state, and to correspond to different scenarios of use, both normal and exceptional.

A fuller account of the principles by which such ISMs can be created is the subject of the next section. Their application will be illustrated with reference to an ISM for the use of an actual digital watch.

3 ISMs and the Representation of SEMI Aspects of State

This section describes and illustrates the way in which an ISM to represent the use of an IA can be constructed. For simplicity, the discussion will focus on the construction of an ISM to represent the use of an actual digital watch, though the principles used are quite general, and have been applied in many different contexts [13, 3, 6, 2].

3.1 ISMs as Construals

There is an intimate connection between an ISM to represent the use of an IA and the explanatory account that an expert, such as the designer of the IA, might give of its use. For instance, when the user first takes charge of the digital watch, they typically carry out a sequence of steps that involve consulting the SEMI aspects of state. They may change the internal state by inserting the battery, determine when the watch is in the `update_time` mode, consult the current time, set the time on the watch, then return the watch to `display_time` mode. In interpreting these actions in cognitive terms, we shall focus on the way in which SEMI aspects are correlated in the states that are visited, rather than on the sequence of steps as a recipe. For instance, whilst in the process of setting the time, the user may contemplate a state in which (in their view) the actual time is 12.30pm, the watch explicitly shows 12.28pm, the watch is in `update_time` mode, and there is a battery in it, so that the time kept by the watch is being updated.

Should the user make a mistake in setting the time (as when setting the watch to 12.30am rather than 12.30pm), the expert will typically be able to construe the error in similar terms: perhaps during the update the user thinks that the watch shows 12.28pm when in fact it shows 12.28am. The explanation for the user's interaction is framed with reference to observables that disclose the SEMI aspects of state, the user's expectations about the ways in which changes to these observables are interdependent, and the user's notion about what agency is operative. For instance, the user expects to be able to exercise control over the mode of the watch (agency), expects that if the mode is `display_time` the display will reflect the internal value of time (a dependency) as recorded and updated by the watch (agency), expects that on leaving the `update_time` mode to enter the `display_time` mode the internal time as kept by the watch will have been appropriately updated (agency).

The concept of *construing* the user activity that is informally introduced here is fundamental to the creation of an ISM. In studying the use of the watch it can be applied in many different ways. The expert construes the user's interaction with the watch, whilst the user simultaneously construes the states and responses of the watch. Different construals might be applied by the expert (respectively the user) to account for one and the same behaviour of the user (respectively the watch). In choosing to set the watch to 12.30am rather than 12.30pm, the user may be resetting the watch to reflect crossing the dateline, for instance, and the expert be mistaken about the current time (part of the situational state), rather than the user about the explicit state of the watch. If the watch keeps accurate time, it may seem appropriate to declare that the time on the watch depends on the current time, but this is a construal that would be confounded by taking the watch from one time zone to another. A watch that kept time by using the principle of the sundial, or exploited GPS to reset its time when moving between time zones would demand a different construal from a standard digital watch.

3.2 Developing an ISM for User-Artefact Interaction

Constructing an ISM involves identifying a family of observables and dependencies between them and finding ways to represent the current values of these observables using a suitable metaphor. In the modelling tools that we use to construct ISMs, families of observables and dependencies are represented by scripts comprising variables and definitions ('definitive scripts'). Where appropriate, the values of these variables are visually represented on the screen in geometric or iconic fashion. Within the modelling environment, there is an automatic mechanism to ensure that the values of variables are at all times consistent with their definitions, and with their associated visual representations (if any). The updating activity associated with this dependency maintenance is simpler than a general constraint satisfaction mechanism — it relies only upon propagating evaluation through an acyclic network of dependencies. The scope for distributing the ISM afforded by our modelling environment is an additional feature that has an essential role when we need to represent 'the same' observables as seen from the perspective of two different observers. In modelling the use of the digital watch, for instance, it is necessary to distinguish between the time as recorded by the watch and the time on the watch as *registered* by the user.

Constructing an ISM for the Digital Watch Figures 4 and 5 together depict a distributed ISM to represent the use of an actual digital watch. Figure 4 represents those aspects of state that relate to the 'objective' state of the watch itself. In modelling an IA in isolation, the relevant observables typically refer to the explicit and internal aspects of state. When taking account of its use, these observables are complemented by others that refer to the mental and situational aspects of state. By way of illustration, the observables in Figure 4 can be classified as associated with explicit and internal aspects of state. Sample observables to represent the explicit aspects of state refer to the digital display, the buttons and the alarm sound. Those associated with internal state include the time maintained by the watch and by its stopwatch subcomponent, the alarm settings that determine whether and when the alarm is triggered to go off, and the power level in the battery. Where the explicit state depends directly upon the internal state in normal operation of the watch, as when a bell icon appears on the watch face when the alarm is set, it is natural to conflate the corresponding internal and explicit observables. Though it seems pedantic to do otherwise, the distinction is significant in certain contexts. A watch engineer would always recognise the possibility that an explicit observable (such as the bell icon) could be inconsistent with the internal observable it is intended to reflect.

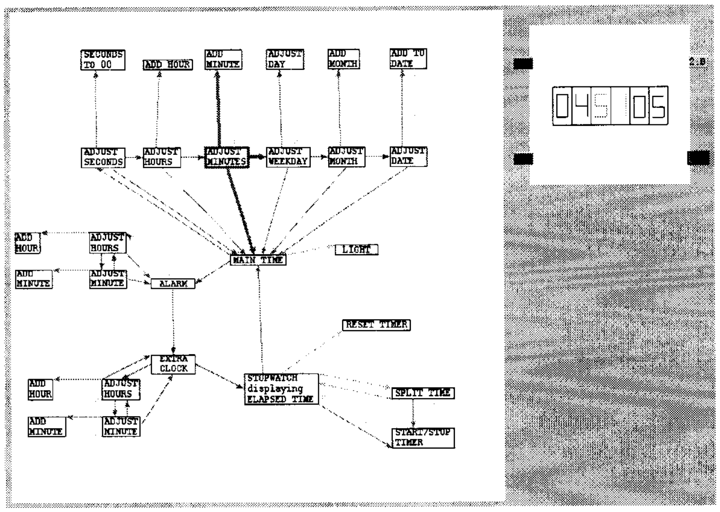


Fig. 4. Internal and Explicit Aspects of State in Digital Watch Use

Changes of state within the digital watch, such as updating the time, are represented in the ISM by redefining the values of observables in the definitive script. Before an agent to perform this update automatically has been introduced into the ISM, it is possible for the modeller to emulate the state changes that a user of the watch might observe in a simple and direct manner by updating definitions manually. The epithets 'simple' and 'direct' here refer to the fact that a single redefinition will accomplish what is construed to be an indivisible change in the state of the watch. For instance, because the dependencies within the script faithfully reflect the dependencies between observables of the actual watch, a single redefinition to increment the internal time will automatically have the expected effect of ('simultaneously') updating the time as displayed in the `display_time` mode. The autonomous capacity of the watch to change state can be captured in the ISM by introducing agents that are primed to redefine the values of variables when certain preconditions are met. When using our modelling tools, these are represented via triggered procedures that are called whenever the values of specified variables are recomputed. Examples of such agents in the digital watch ISM include the mechanisms that update the internal time and that control the setting and sounding of the alarm.

A useful model of the digital watch has to include a representation for the internal state that is associated with its different modes. This aspect of the watch state is generally indicated on the display by an explicit observable in the form of a mnemonic, such as AL (for 'alarm mode'), that appears on the face. To be able to observe and manage the mode of the watch, it is necessary to be familiar with the mode-transition diagram. The nodes of this diagram are defined by the abstract modes of the watch and its edges by the transitions between these modes as specified by button presses. This diagram is the edge-coloured digraph to the left of the digital watch in Figure 4. In interpreting Figure 4 in its entirety, it is appropriate to consider the relationship between explicit and internal states of the watch as they are conceived by the watch designer, and communicated to the user via the user manual or by secondary notations [8] on the watch.

No observables to represent the situational aspects of state are included in the ISM shown in Figure 4. Such observables would be an indispensable ingredient of the ISM if the function of the watch itself were to be dependent on its environment, as in the 'watch with automatic GPS reset' mentioned above.

Constructing an ISM for the Use of the Digital Watch In modelling the use of the digital watch, the user's awareness of a whole range of SEMI aspects of state has to be taken into account. As will be explored in the next section, there is a sense in which creating an ISM to represent a user is an impossible task: it is at any rate a task that can never be completed, that can always benefit from additional empirical evidence, and that is confounded by the elusive and possibly ill-conceived notion of 'a typical user' (cf [5]). By its nature, an ISM is peculiarly well-suited to this difficult and obscure role: it is of its essence incomplete, acquires its significance through interaction, and has no formal functional or behavioural specification. It is equally apparent that the designer of a digital watch *does* have an notion of 'appropriate use' of the watch by an idealised user in mind. Such a user can reasonably be taken to be committed to using the digital watch in strict accordance with the designer's canonical model of use. To fulfil this role, it is not necessary for a user to be familiar with the entire functionality of the watch, but only with that part that relates to the specific uses of the watch that are to be exercised.

The observables and agency that define the internal and explicit aspects of the watch state (as represented in Figure 4) are objective in nature, and at some level of abstraction reflect the designer's or the engineer's conception of the watch. The observables that represent the mental aspect of the state as perceived by a user are more controversial, and potentially more subjective. The role of these observables is to reflect the distinction between the current mode of the watch (as might be established by an electronics engineer through reference to its internal state), and the mode of the watch that the user presumes the watch to be in. The metaphor for the mental aspects of state that best suits an actual user's conception of the watch will be a matter for empirical determination, but for the idealised user, the abstract mode-transition diagram conceived by the watch designer can supply the appropriate framework. To this end, the partial — but so far as it goes perfect — knowledge of the watch use is depicted in Figure 5 by the highlighted subset of the complete mode-transition diagram. This can be interpreted as representing the part of the watch functionality with which the user has become familiar.

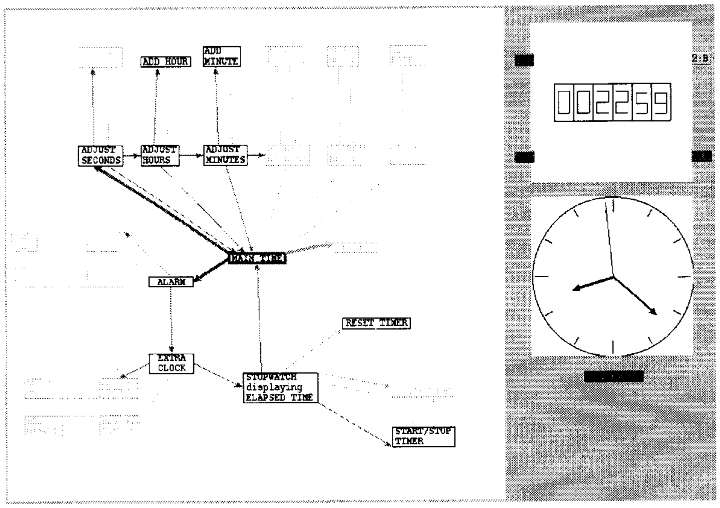


Fig. 5. Situational, Explicit and Mental Aspects of State in Digital Watch Use

The situational aspects of state associated with use of the watch vary according to which particular mode of use applies. In so far as the standard time-keeping function of the watch is a persistent concern of the user, the current time and location are always part of the user context. In the ISM, this is reflected by the presence of the analogue clock to record the current local time in Figure 5. Other situational observables become significant when specific user activities involving the watch are being studied, as when the stopwatch is being used to record the finishing times of two runners in a race (as discussed in Section 4 below).

3.3 The Identity of an ISM

The concept of importing new observables into the ISM according to what use is being made of the IA raises some fundamental issues about the integrity and identity of the ISM. An important and essential distinction between the ISM and a more conventional computer-based model is that it is inappropriate to identify the ISM with any particular fixed selection of observables or patterns of state transition. The ISM can only be explored state by state, and it is a matter of interpretation as to whether any particular transition should be seen as 'changing the ISM'. It is clear that many state transitions — such as the incremental changing of the time in normal operation — are to be viewed as changing the state of the watch rather than substituting a new watch. Other transitions, such as adding another button, are hard to interpret as anything other than changing the watch. It is also clear that there may be — and indeed always will be — observables of the actual watch yet to be taken into account in the ISM that might usefully be introduced. For instance, because of power considerations, the display might become fainter when the alarm is sounding. In general, any attempt to fix the identity of the ISM by declaring the specific states and state transitions it can undergo undermines the semantic role it serves for the modeller. The meaning of the ISM is experimentally mediated, and the modeller always has discretion over the interpretation of state transitions, whether they are associated with introducing new observables or giving different values to existing observables.

It is in this spirit that the ISM depicted in Figures 4 and 5 can be regarded as reflecting the designer's construal of the digital watch. It represents the package that the designer consciously and explicitly offers when handing over the watch and its manual to the user. The cognitive processes of a user who experiments with the watch without first consulting the manual, the possible consequences of malfunction of the watch, and the arcane purposes to which the watch can actually be put (such as serving as the function of a protractor or a paperweight, for instance), are issues peripheral to the designer's remit. The rich variety of adaptations of the basic ISM that are accessible to the modeller can serve to represent this penumbra of actual rather than idealised interactions of the watch, as will be illustrated in the following section.

4 Illustrating the Use of the ISM

An ISM does not only itself serve as a construal — it can also be construed. First and foremost, the ISM is to be construed *as a construal*, but where the interaction and situation are appropriate, an ISM can be interpreted as a conventional computer program or as an IA for which specific user activities have been identified. The choice of interpretation adopted depends upon whether the interaction with the ISM is construed as open or closed user-artefact interaction.

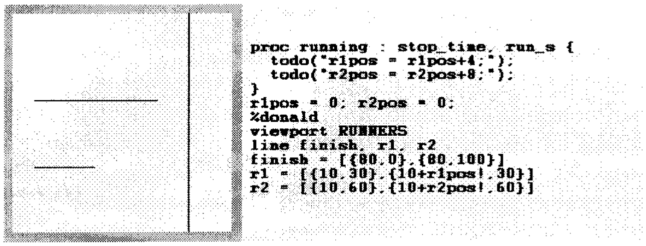
As the ISM depicted in Figures 4 and 5 illustrates, the way in which the modeller construes an ISM is both flexible and highly significant. The visualisation associated with the mode-transition diagram in Figure 4 is to be interpreted as representing the mode of the watch as it is determined by its internal state. As it appears in Figure 5, what is essentially the same visualisation refers to the state that the user projects on to the watch — it represents the mode the user thinks the watch is in. The choice of construal determines the dependency relationships recorded in the script and the kind of agency that can be exercised over them. In Figure 4, the only change of state in the mode-transition diagram that is to be expected in normal operation of the watch results from a change to the internal mode of the watch initiated by a button press. Other changes of state in this diagram have to be interpreted as more radical in nature. For instance, illumination of the watch display that was not accompanied by the appropriate change of internal state might be construed as a watch malfunction, or the addition of a new node to the diagram construed as a redesign of the watch. In Figure 5, changes of state associated with the mode-transition diagram are less constrained: it might indicate that the user had come to a new conclusion about the current mode of the watch, or had mastered a new aspect of its functionality.

There are numerous motivations for construing an ISM such as that in Figures 4 and 5 in different ways. Different scenarios for use can be represented by a wide variety of modes of observation and agency. There is an entire agenda associated with teaching the use of the digital watch, and another with communicating about specific designs and design principles. From the perspective of stopwatch design alone, many further issues could be addressed. A school PE teacher, a sprinter and a long-distance runner all have different requirements: the teacher can operate the stopwatch whilst stationary, but the runners must use it whilst in motion; the sprinter needs to start and stop the watch in a way that does not interfere with their action; the long-distance runner would appreciate a watch that displays the time together with current heart rate.

Adapting the ISM to suit the whole range of useful construals involves reconfiguring the dependencies that link existing observables, the agency that can be applied to them and the way that they are distributed for observation. It can also mean introducing new observables together with dependency relationships to integrate them into the existing state. Making due allowance for the limitations of our current modelling tools, the ease with which such adaptations can be carried out is determined by the quality of the ISM as a construal. In particular, our ISM of the use of the watch in Figures 4 and 5 is easy to adapt to new purposes to the extent that (at the appropriate level of abstraction) the ISM is a faithful reflection of how the watch works, and the purposes to which we want to direct the redesign or re-use of the watch are compatible with the way it works. Some specific adaptations of the ISM, with hints as to their possible application, will serve to illustrate this theme. They also show how the balance between situational, mental, explicit and internal aspects shifts according to whether the interaction with the ISM is more appropriately construed as open or closed.

There are many ways in which our distributed modelling environment can be used to study interaction with the digital watch. Different scenarios can be set up by distributing sections of the definitive scripts in Figure 4 and 5 to mediate the actions and observations of demonstrators, observers and learners. For instance, button actions demonstrated by one user could be communicated to models on other users' screens. Alternatively, one agent in the network could be configured to monitor and record button presses automatically in the role of a passive observer so that learners' responses could be analysed later without their direct involvement. Learning with a computer based artefact can be less costly than interaction with a real world artefact since only a computer-based representation of the artefact under study needs to be distributed. Other possible ways of using the digital watch artefact in an educational environment are discussed in [13].

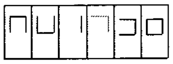
The ISM for the digital watch depicted in Figure 4 is extensible. We can add new functionality to the watch very simply by including a few definitions. The functionality of watch model was derived from a real watch but was originally modelled with some features omitted in order to show how they could be incorporated at a later time. In this case, a 'second clock' feature that enables the user to keep track of the time in two different time zones simultaneously was left out and subsequently added 'on the fly' by introducing a short supplementary script. As another example, the watch — as designed — demonstrated viscosity [8] when the time was incremented beyond the target setting in the `update_time` mode. A small auxiliary script was sufficient both to remedy this problem and to make the necessary modifications to the mode-transition model associated with the internal state of the watch in Figure 4. Different uses of the watch can likewise be introduced through adding observables to the situational state. To this end, the simple animated line drawing to represent two runners competing in a race shown in Figure 6 can be added to the display. The watch user can then demonstrate how the stopwatch functionality of the digital watch can be used to record the finishing times of both the runners.



```
proc running : stop_time, run_s {
  todo("r1pos = r1pos+4;");
  todo("r2pos = r2pos+8;");
}
r1pos = 0; r2pos = 0;
%donald
viewport RUNNERS
line finish, r1, r2
finish = [{80,0},{80,100}]
r1 = [{10,30},{10+r1pos!,30}]
r2 = [{10,60},{10+r2pos!,60}]
```

Fig. 6. Situational Observables — Timing Two Runners

The user-artefact interactions that neighbour on normal use include situations where environmental or perceptual obstacles interfere with the standard processes of observation. As a simple example, consider trying to determine the time from a digital display that is partially obscured by an item of furniture — for instance, as in observing a clock whilst lying in bed. A period of consistent and careful observation is typically needed before we can work out what the current time is, based on the partial displays of digits we can see, our knowledge of the pattern that governs the changes to these digits and our contextual knowledge of the approximate time of day that we believe it to be. The subtlety of observation in this scenario is compounded when we consider that the sleepy observer is liable to pass in and out of consciousness. One representative from the six sets comprising three simple redefinitions needed to transform the display appropriately is listed in Figure 7. The boolean values in this listing could be replaced by predicates to take account of (e.g.) how the position of the observer affected clock visibility.



```
%donald
within led1 {
on3 = false
on5 = false
on7 = false
}
```

Fig. 7. A Partially Obscured Digital Display

5 ISMs, Cognitive Dimensions and Invisible Computing

The construction of ISMs and the study of CDs share a common agenda with respect to understanding cognitive aspects of information artefact use. Both approaches aim to complement approaches based on aesthetic concerns [9] or counting user actions [4] by addressing interaction in conceptual terms, but they are quite different in character. As the previous section illustrates, user-artefact interaction can take such diverse and subtle forms that an empirical study of actual uses throws up far more information than it is feasible to document. CDs address this problem by abstracting from the specific experience of a user-artefact encounter, proposing general activities and issues to target in analysis. The application of ISMs involves creating an artefact that can implicitly offer a representation for this experiential knowledge.

CDs and ISMs put their primary emphasis on different kinds of user-artefact interaction. CDs focus on user activities of an established artefact, ISMs on modelling that is conceptually prior to the identification of the mode of use (if indeed there is to be any such identification). There is a useful parallel to be drawn with conventional programming — CDs are analogous to techniques for program comprehension, evaluation and testing, whilst ISMs are oriented towards the identification of program requirements. The development of IAs or programs from an ISM is an empirical activity that involves the identification of stable patterns of behaviour (cf. the empirical development of a manufacturing process in [6]). The analysis of SEMI aspects of state exemplified in Figure 4 and 5 is relevant to the study of the artefact throughout this development, and converges to a view of IA-use similar to that described by Norman [10], in which the designer's model and the user's model are mediated via the system. CDs also offer higher-level abstractions to assist the analysis and comprehension of user-artefact interaction: some of these are associated with higher-order dependencies that could be introduced into EM, subject to placing them in their appropriate experiential context (cf. the incorporation of assertions about program state into an ISM in [3]).

The deconstruction of the user activities involved in creating an ISM helps to expose issues that relate to CDs. The ISM represented in Figures 4 and 5 supplies a useful environment in which to explore the CDs of the watch. For instance, both the viscosity associated with decrementing the time whilst setting the watch, and the remedy associated with adding a decrement button, are reflected explicitly in the ISM. Many issues of hidden dependency are connected with the relationship between different aspects of state, and between explicit and internal aspects in particular. Creating ISMs can be a useful vehicle for demonstrating CDs and communicating about them. In exploring CDs, there are some advantages in being able to navigate the state space more freely than the actual information artefact itself allows.

Whether these points of contact between the use of ISMs and CDs are significant depends crucially upon the nature of the user-artefact interaction under consideration. If the CD analysis is directed at closed user-artefact interaction there is no particular advantage to be gained from the ISM modelling approach — indeed, there are optimisations to be made by constructing an OO model of the IA. In this case, the flexibility that the ISM affords primarily relates to issues of redesign of no specific relevance to CDs. There is more potential for interesting interaction between CDs and ISMs where the user-artefact interaction is open, or the CDs analysis is targeting users with different motivations and degrees of understanding. In this case, we can better exploit an ISM to construct models of use neighbouring on canonical use in the 'space of sense' [1].

Norman's vision of the future of computer technology [11] embraces information appliances each expertly engineered for its precisely specified and documented use and cooperating to support complex human activities. Odlysko [12] identifies problems of compatibility and intercommunication as major obstacles to the realisation of this vision in the short-term, and relates this to the trade-off between flexibility and ease of use. These discussions are framed from a perspective of closed user-artefact interaction, where ease of use is associated with 'delivering specific functionality in a way that is self-evident to the user' and flexibility is to be interpreted as 'offering more general functionality'.

The concept of an ISM as a vehicle for open user-artefact interaction relates to Norman's *invisible computer* culture in two respects. On the one hand, it suggests a framework to assist the identification of requirements and subsequent development of compatible and communicating information appliances. On the other, it points to a complementary vision of an alternative culture based on open user-artefact interaction. In this scenario, users will be educated — as in learning a natural language — to create their own personalised individual information artefacts for self-expression. In some respects, the significance of these artefacts will remain as private and subjective as a written document can be. With the will to understand each other, and through effort and cognitive demands similar to those we make when communicating in natural language, it will be possible for users to configure these private information artefacts to allow communication.

6 Conclusion

New technologies are changing the character of human-artefact interaction. They compel us both to confront and to establish more intimate relationships between human cognition and technology than were conceivable in the past. To this end, it is essential to give more support to an open user-artefact interaction perspective. The use of ISMs to model SEMI aspects of state is a promising direction for future research on this theme.

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