Mode-switching in multimodal systems

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Abstract—**Mode-switching allows multi-modal computer systems to adapt their mode of interaction to their users' ongoing activities and changing circumstances, yet although largely unacknowledged, this can create problems in interactional inconsistency across modes at the user interface. We discuss some of these problems and present interaction design solutions, using examples.**

Index Terms—**Multimodal, user interface, interaction design, flexibility, consistency.**

I. Introduction

As we move from fixed computer systems to mobile, embedded and networked computer systems, multi-modal interaction becomes progressively more important as users cannot solely rely on visual user interfaces, or where a single modality of interaction will constrain the activities that users are able to perform [1], [2]. These could be where the environment of use is too noisy to support verbal interaction, too bright to support reading from a screen, where they are unable to move towards a location-fixed interaction device, or any range of other possibilities. *Mode-switching* is a technique that allows computer-based systems to move between different modalities of user interaction, allowing the selection of a medium that is appropriate for a user's ongoing activities and their changing contexts of system use. However, this technique presents its own problems in the design of the user interface, and forms the topic of this paper.

Mode-switching systems allow users to move between different input and output devices, as and when necessary: they 'allow users to exercise selection and control over how they interact with the computer' [3:p.71]. A good example of a setting in which multiple methods of interaction are used to undertake the same computational task is illustrated in the design requirements of the Millennium Home system (more fully documented in [4]). This system monitors the activity patterns of residents in their own home, and attempts to identify whether they have encountered a critical health problem. If the system detects an anomalous behavioural pattern (e.g. a fall, unusual inactivity, medication not taken), it will engage in a dialogue with the user to determine if they require a call for outside help to be made. It is this interaction with the user that we are interested in here: depending on where the user is in the house, what they are doing, the nature of the detected problem, and any ongoing changes to the ability of the user to interact with the system, a particular modality may be (or become) inappropriate.

The example of the interaction problems faced in the design of the Millennium Home system is an interesting one, because, despite the apparent simplicity of the system, a number of problems have arisen in designing it. The system must adapt to its users needs, yet retain a level of usability that allows the residents of the home to interact with it meaningfully. One of the reasons for the problems in interface design is that the different sensory modalities that we have as users (visual, auditory, tactile, etc.) have very different physical and cognitive properties associated with them (e.g. ephemerality, noticeability, and the relevance expectations that users have of them), and these mean that the interaction cannot simply be 'ported' to another modality. A simple example of this can be seen in the use of pull-down menus: a long menu may be acceptable for visual interaction, whilst the same menu items cannot easily be recalled when that same information is presented as a spoken list.

II. Interactive multimodal systems

Multimodality in human-computer interaction offers a number of potential advantages to users. These include enhanced robustness in the quality of the interaction that is experienced by users [e.g. 3], in improvements to task-action mappings by linking the method of user interaction to the computer's representation of the task [5], in its application in universal usability across a wide range of user ages, abilities and needs [6], and in its interactional flexibility across the available forms of input and output media [e.g. 3]. Although what we have to say here draws from and speaks to all of these areas, our intention is primarily to addresses the final point, in improving interactional flexibility.

There is a good deal of confusion, both in the popular and academic literature as to what constitutes a multimodal system, and this is clearly an important distinction that needs to be determined prior to this discussion. The term is often confused with multimedia (using more than one medium of data presentation, i.e. of computer output) or multiple device use (using more than one method of collecting user actions, i.e. of computer input devices). To take the Oxford American Dictionary definition, the term 'modal' means 'a way or manner in which something occurs or is experienced, expressed, or done' or 'an option allowing a change in the method or operation of a device', with the addition of the prefix 'multi-' offering a plurality of the methods noted. However, in their use, a plurality of methods means more than

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simply offering the user a choice of input *and* output media, but linking these together into a form of interaction style and dialogue structure that is appropriate for the devices, media, activity, user inclination, and environmental context. This design of an appropriate interaction style and dialogue structure is challenge enough for a singe mode of operation, but becomes greatly more complex where users can select from multiple methods of interaction.

One of the frequently purported key benefits of multimodal systems, across a range of application domains, is that of 'robustness'. Multimodal systems offer the opportunity to increase the accuracy of interaction in otherwise error prone activity settings and interactional contexts. They are able to do this by combining interactional modalities (typically just user input) to help disambiguate and refine a user's interactional behaviours in the face of weak or contextually hard to generate input signals. This is possible because users can adapt the media that they use in their interactions to make best use of the modalities of those media, or reactively move to another medium if required (for example, see [7], [8], [9]). Indeed, there is much evidence to suggest that combinations of complementary technology can be used to increase input recognition rates (e.g. [10], [11], [12]), although these have mainly been examined with reference to speech and direct manipulation/gesture. Examples in the literature include systems such as Bolt's [13] Put-that-there, using voice and gesture to control object manipulations, and speech and pen input, such as Oviatt *et al.'s* Quickset system [1] to generate and manipulate text. In these systems, a change in user input mode or use of a combination of input modes results in some change in output to the user who must accommodate to this change. Yet this point has been largely neglected, with the bulk of research effort placed on supporting the computational demands of interpreting and combining multiple streams of user input.

We argue that this 'complementarity' of modes in simultaneous support of action to improve the robustness of recognition is not always appropriate, or necessary, and it may be something of a specialised requirement for particular forms of computer-based activities. Whilst it may be useful to improve the robustness of recognition in an interaction, it may be more useful to be able to shift between single modes of interaction (either as input or output). How users move between different modes in their interaction, and how they understand the movement between these different modes are extremely important questions to ask from the perspective of interaction design, because these are what constitutes a good user experience for them, and what makes the system useful in meeting their goals.

III. Switching Amongst Dialogue Modes

A. *Consistency and adaptation*

Whilst there is evident value in the use of multimodal interaction to support recognition through the complementarity of the various modalities working simultaneously (or when coupled together), this is only a part of the more general value that multimodality can bring to the utility of interactive systems. Although it is recognised that multimodal systems allow switching between modes, giving '…users the flexibility that is needed to accommodate the continually changing conditions of […] use' ([3], p.71), this is usually glossed over and trivialised in the absence of a discussion of what this really means for interaction, at least in terms of design strategies and guidelines.

Mode-switching involves the use of a *single* interactional modality at a time. This allows the selection of an interaction style and medium that is appropriate to the current setting or activity, and which works around its constraints (such as its acceptability or environmental noise). Our own experience of mode-switching shows that, apart from a few simple examples, switching between modalities is not a simple matter. There are examples where mode-switching may be relatively simple and does not require sophisticated interaction designs, such as selecting whether to use a mouse or a voice command to control a menu selection in a word processor. However, an example of where this may be harder to achieve without a more sophisticated interaction design can be seen in the Millennium Home system. In the Millennium Home, interactions are drawn out over extended periods of time, during which the context of the interaction environment may change and the user may be interrupted by other activities, and where the required interaction may involve multiple and sequential option selections or responses. This is not a unique problem to the Millennium Home, and is one that will become increasingly prevalent as embedded and ubiquitous computer systems [14] become more commonplace, because these are core features of ubiquitous computing use.

Systems that support mode-switching can be described as having 'adaptable' or 'adaptive' user interfaces. The difference between these terms is that adaptable interfaces are generally seen as allowing user selection of an interaction mode, whilst adaptive interfaces are generally seen as allowing the system to select the mode of interaction. Both can be viewed as allowing mode-switching, although each offers somewhat different problems to interaction designers. The former requires the system to be able to adapt its interactions and dialogue structures to the requirements of the user without requiring the user to pay a large cognitive cost in using the new modality of interaction. The latter requires the system to present information to the user in such a way that they are able to determine that a change in the mode of interaction has taken place and are able to understand enough about the current internal state of the system to interpret any ongoing interactions. For the purposes of this paper, we will be considering systems that are both adaptable and adaptive (such as the Millennium Home), because this addresses more a more powerful approach to interaction (i.e. systems that can both alter their interaction modes and be altered offer a high degree of functionality), but also because this allows us to discuss the complexities arising from both approaches. Where the discussion below affects only one form, this is explicitly noted.

There are few documented instances of mode-switching interfaces, so it is useful here to consider what constitutes an adaptive/adaptable interface. According to Kantorowitz and Sudarsky, an 'adaptable user interface is defined as an interface that:

- supports a number of different dialogue modes…,
- allows the user to switch between dialogue modes at any time, i.e., even in the middle of a command;
- makes the switch between dialogue modes smoothly and naturally;
- makes it easy for the user to learn how to use the different dialogue modes…' [15:p.1353].

We can extend this to cover system-initiated (i.e. adaptive, behaviour) to add another definitional point, in that they may also:

- allow the system to switch between dialogue modes at any time, i.e., even in the middle of a command, dependent on the level of urgency or importance of the need for user interaction with the system, and which is informed by user activity over an extended period of time.

As can be seen from Kantorowitz and Sudarsky's last two points, making smooth transitions between modes and learning how to use the different modes is important. These are perhaps *the* critical usability issues to address in the interaction design of mode-switching systems. Being able to switch dialogue modes in a way that is simple to understand and easy to learn is crucial in an environment where users may be simultaneously engaged in other, unrelated activities, where system support and learning resources are not at hand, and where there is a need for users to make a quick response to system requests or environmental circumstances. There is also an important matter of note to be considered in the second and our final point, that there can be a 'switch between dialogue modes at any time… *even in the middle of a command*' (my emphasis). This, as we will discuss, is a major problem for interaction design and one that appears to have been neglected in previous design discussions around multimodal systems.

B. *Issues for interaction design in mode switching systems*

What then are the important factors in determining the usability of interaction in multimodal systems? We have identified that the switch must be smooth and natural, but also that this switch must be possible at any time, including during an interaction sequence, something that may potentially conflict with the smoothness and naturalness of the interaction experience. Interaction design therefore needs to take account of the various modes of interaction available, and their (different) properties that may affect the course of an interaction sequence. Following this line of argument, one of the crucial problems in designing a mode switched multimodal system is determining how the selected mode of user interaction maps onto the *methods* that users can employ to achieve their intended system outcomes (i.e., in meeting their goals). Selection of an appropriate mode is clearly going to be an important factor in determining the users' performance in their operation of the system and their satisfaction with the nature of the interaction. There is good empirical evidence for this: in a study of task completion time, error reduction and system acceptance in multimodal systems, it was found that improvements could be made in design if the responses of the multimodal system were matched to its users' perceptual motor skills [10]. Put more bluntly, the selected mode of interaction affects the usability of the computer system.

As we have seen, different modes of interaction have different properties and potentialities, and this can have an impact on their incorporation into an interface design. Thus, for example, from the perspective of the user, navigation through verbally presented menu structures is very different to navigation through visual menus, due to processing of the signal in the cognitive system. The reason for this is that auditory cues are short-lived, but are good for making users aware of state changes to the system (i.e. they afford reminding *in* time). Conversely, visual cues are useful in that a system's state is always available and accessible (i.e. they afford reminding *over* time), but state changes may be missed if a user's attention is elsewhere. Similarly, user input to the system is affected by the modes used; for example, gesture-based input may require little effort on behalf of the user, but can be ambiguous and hard for the system to interpret, whilst on the other hand, direct text entry or mouse selection can be less ambiguous, but generally requires a user's full attention and must be carried out from a specific location.

Because the properties of the various modes of interaction are different, it is likely that for many system interactions, the use of different input and output media may require different dialogue structures to achieve the same outcomes/user goals. A simple transformation of the interactional medium will not necessarily be appropriate, because the form and content of the interaction may need to be adapted to fit the constraints of that particular interactional modality. Thus, as a simple example, reminders to do something that are presented visually might require multiple presentations if the interaction switched to output over audio. However, to do this without losing *consistency* in the interface design is problematic: this is important because consistency is recognised as a (and possibly *the*) critical factor in good interaction design [5]. Empirical research in the field of human-computer interaction tells us that the use of different interaction methods, even when carried out in the same medium (for example, visually, using direct manipulation/'drag and drop' [16] or a command line interface) to achieve the same outcome, can be confusing to users as they may have learnt one method of interaction and have expectations of system behaviour that are *not* met through other methods of interaction. In this respect, the 'flow' of sequential interactions in a mode-switching system (for example, the content, location of presentation and frequency of feedback) must be in line with the users' expectations, or they may fail to understand what has occurred in their interaction with the system (such as whether their input has been recognised, where they are in an interaction sequence, if their request has been acted on, and so on).

The problem of insuring consistency in the interaction is greatly magnified if the mode of interaction changes *during* the interaction sequence. When the methods of interaction for the different modes do not neatly map onto one another, how can the system adjust its dialogue to meaningfully continue its interaction with the user, without restarting the interactional sequence again and the consequent confusion to the user that this might cause? Thus, where regular feedback may have been given, or multiple presentations of options were previously made, following a mode switch, these may not be conducted in the same way that they were, perhaps just moments before. This is an issue that needs to be extremely carefully considered in the design of a system that allows within-dialogue mode-switching, as called for by Kantorowitz and Sudarsky [15].

When switching between modes is caused by the system adaptively, and is not selected by the user (for example, occurring in response to a failed request for user input), there can also be problems in determining the appropriateness of the interactional modality selected. The computer system needs to be able to determine a mode for the interaction, whilst allowing users to switch from this mode to suit their own context-specific needs or requirements. In the case of the Millennium Home, where the users of the system might be unable to use a particular interactive medium or method, for reasons of accident or illness, or their mobility or comfort in using it, mode-switching offers a powerful adaptive tool for enabling users to control the system. However, the implementation of a system that requires complicated interaction sequences for the user to verify the state of the interaction could potentially present its users with a burdensome level of interactional complexity. Starting each sequence of interaction dialogues with an explicit report of the current state of the system, particularly on a small-screened device or over audio could greatly prolong simple interactional tasks, with a likely concomitant falloff in user acceptance, and potentially even a life-threatening delay.

This problem, then, is clearly one that addresses the interaction, or interface design, of multimodal systems. We have not attempted to do what several research projects have attempted to do in this area (e.g. [2], [17], [18]), which is to automate the interaction dialogues, either through the use of interactional grammars or an 'intelligent' systems approach. This can be achieved, for example, by creating a 'mode independent representation' of the next dialogue term [2]. By using rules to generate interactional content that is coordinated across the various modes of communication to the user, it is possible to dynamically shift dialogue across modalities. These intelligent systems techniques can resolve mode-shifting problems such as maintaining the semantics of the interaction, but they *cannot* resolve problems arising from interactional inconsistencies across the different modalities used, and are unable to address key aspects of the usability of the human-computer interface.

The pattern of mode shifting interaction that we propose is predefined by the designer, in the same way that an information architect might define the navigational structure of a web site. There are a number of theoretical and pragmatic reasons that we have chosen this approach. On the theoretical side, control over the consistency of interaction is best left to designers who can specify and refine it according to the particularities of the use conditions and the modal constraints. We recognise that some of these 'rules' of consistency across modes can be developed within intelligent systems, but like all general purpose rules, they are likely to be inappropriate under particular sets of use conditions. Moreover, testing the usability of intelligent systems is hard, if not impossible: when the system can act autonomously, it is hard to ensure that all conditions of its use are tested. Finally, until we understand how to design consistent multimodal interactions using a controlled approach (i.e. when the variables under investigation are under the control of an evaluator), we will be unable to automate these interactional components in a principled way that is informed by empirical research. From a pragmatic perspective, as multimodal systems become more prevalent, it is unlikely to be feasible for many commercial product developers to develop a bespoke intelligent interactive system in addition to developing the system's underlying functionality. Indeed, as we demonstrate, it is not necessary to do so.

C. Strategies for designing interaction in mode switching systems

Modal switching within an ongoing interactive sequence is likely to be problematic for interaction designers because different interactional modes have different cognitive properties. An interaction initiated in the medium of audio with verbal user feedback that later shifts to a screen and button-based mode (either when directed by the user or in reaction to events) will place different demands on the user. Interaction sequences that are optimised for one mode will not necessarily be appropriate for the other, and are likely to require very different interaction pathways for the different modes that can be used. By interaction pathways, we mean the structure of the interactive sequences that compose a goal, be that printing a document in the case of using a PC, or calling or canceling a call for assistance in the case of the Millennium Home.

To graphically illustrate what we mean by interaction pathways, fig. 1. shows a dialogue-independent flowchart of the structure of the interaction design of the 'medication alarm' in the Millennium Home System. This is kept as simple as possible to illustrate the abstract principles that we focus the discussion on. Although complex, the diagram was selected as one of the more simple interaction sequences in the design. This alarm is intended to remind the resident of the home when they have not taken their medication at the time required, and is one of the Millennium Home's simpler interaction sequences. The flowchart demonstrates the possible set of interaction sequences that a user can take through the system. Each arrow indicates a potential path that the user can traverse in an interaction event. In this scenario, information may be presented to the user over a loudspeaker, over a visual display or using a telephone call. Cycling through the system, further attempts are made to elicit a meaningful response from the user, noted in the fig. 1 as Comm(n), with an increment in (n) after each attempt to communicate. At various points, other alarms may be

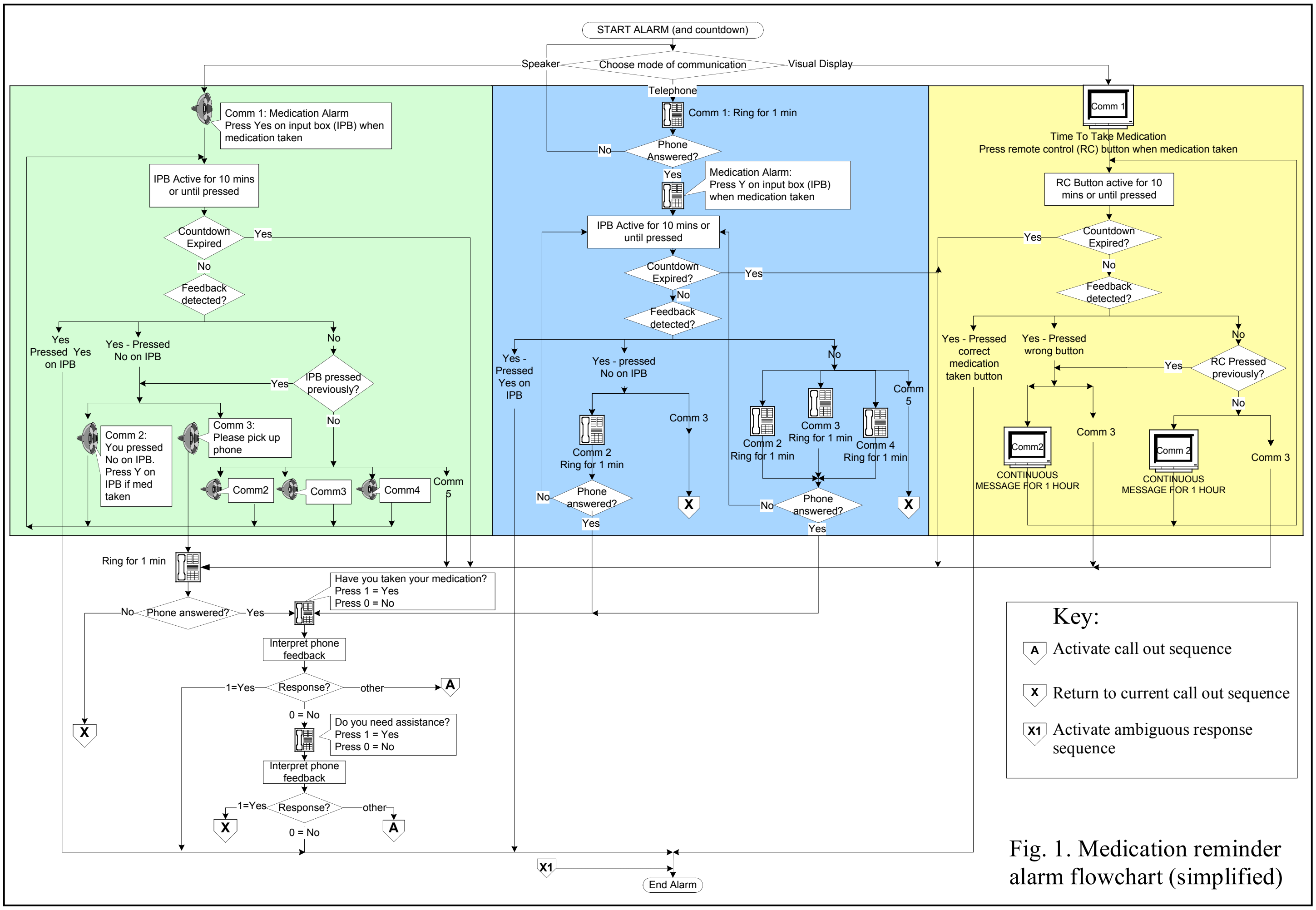

Fig. 1. Medication reminder alarm flowchart (simplified)

activated or returned from (labeled A, X and X1), which are not represented within the figure. It is not important to understand the detail of the design, but the figure demonstrates the sequencing across the different interaction modalities (i.e. the states and state transitions), and how we have attempted to design the interaction flow to take account of the constraints of each mode of interaction. Please note that the design of the completed system is not easily visualisable, as it is distributed and embedded into the fabric of homes, and an abstract representation is the clearest way to demonstrate patterns of interaction with the system for the purposes of this paper.

Close inspection should also demonstrate how we have also attempted to build in a consistent method of interaction across these different modalities, such as the number of warnings given, the number of requests for input, and the failure of the user to make an interaction in any mode leading to it reverting to a final common mode of interaction (the telephone). Whilst we do not profess this to be an ideal design, it serves to illustrate what we are attempting to convey, showing what we mean by an interaction pathway, and how various modalities can be integrated into a consistent (in some respects) user interface design. Somewhat counterintuitively, to enable consistency of interaction across modes, it may not be appropriate to ‘optimise’ the interaction designs for each mode independently of one another. The most usable interaction design for a single mode of interaction may potentially cause its users confusion: as users switch to another mode, the new mode may not be able to effectively carry the interaction in a similar interactional structure to the previous mode, leading to a breakdown in the user’s understanding of what is happening. Extending this point, it is not recommended that designers fully develop the interaction design for one mode, then to develop interaction designs for other modes; the interaction designs for all modes need to be developed and refined concurrently.

There is an important question posed in this notion of ensuring consistency of interaction and the avoidance of confusion to the user when a mode is switched. This is how to move between modes of interaction during the course of a dialogue with the system, what we have called ‘within-dialogue mode-switching’. One solution to this is to segment interaction with the system into small sub-units, so that each sub-unit can be completed (or fail), allowing following interactions to be conducted in any other modality. Each sub-unit is relatively self-contained, allowing the user to respond to, or initiate a dialogue, allowing the satisfaction of a sub-goal. Within these units of interaction, the mode cannot be switched, which can only be done at the end of the sub-goal sequence. In the medication reminder alert shown in fig.1, this sub-goal completion occurs either when the user responds to a system-initiated request, or when a timer countdown expires without a user response. Breaking the interaction into small, meaningful segments is a useful method of reducing the confusion that may occur from such within-dialogue mode-switching.

As alluded to above, within our own designs in the Millennium Home, the system actively performs mode switching at points of interaction failure with the user. Within the Millennium Home, we attempted to ensure that the system was 'fail safe', and rather than make assumptions that the user was otherwise engaged and unable to respond, we needed to ensure that the system moved into a state in which help could be called on if the system was unable to evoke a response. This may not, we realise, be necessary or appropriate in all cases, but it is a useful design strategy to consider.

IV. Conclusion

This paper demonstrates that what has previously been largely glossed over as a simple mechanism for moving between different modes to operate computer-based systems, is, in practice, rather more problematic than it initially appears. The core problem for mode-switching systems lies in the area of user interface design, and occurs particularly where mode-switching multimodal systems are developed for ubiquitous environments, or where users are engaged in prolonged and multiple interactions with the system, and when they are multitasking with other activities. Critical issues occur in maintaining interactional consistency when switching across sensory modalities, so that users are able to understand the current state of the system following their interaction with it and to make predictions about the form that future interactions will take. We can resolve some of these problems through the interaction design techniques described, providing good user feedback, consistency of interaction across modes, and segmentation of the interaction sequence into small, sub-units of meaningful communication. Current research threads in multimodal systems design such as automatically generating user interfaces on the fly and combining input streams from multiple modes all give increasing levels of sophistication to the functionality of the device, and potentially can improve the flexibility of situations in which they can be used. What they cannot however do is to provide their users with a method of accessing the system's functionality in a form that is suited to the particular needs of users in the contexts of their interaction.

This paper offers an approach to developing a principled method of developing interaction styles for multimodal user interface designs that goes beyond the computational mechanics of developing novel multimodal input or output components. Whilst these computational mechanisms underlie what we have been proposing, we argue strongly that it is the design of the user interface and not their mechanical algorithms that will determine the usability and eventual usefulness of these systems.

References

[1] S.L. Oviatt, P.R. Cohen, L. Wu, J. Vergo, E. Duncan, B. Suhm, J. Bers, T. Holzman, T. Winograd, J. Landay, J. Larson and D. Ferro, "Designing the user interface for multimodal speech and gesture applications: State-of-the-art systems and research directions," *Human Computer Interaction, 15*, 2000, pp.263-322.

[2] D. Reitter, E.M. Panttaja, F. Cummins, "UI on the Fly: Generating a Multimodal User Interface," in *Proc. Human Language Technology Conference 2004 HLT/NAACL-04*, 2004.

[3] S. Oviatt, "Designing Robust Multimodal Systems for Universal Access," in *Proc. 2001 EC/NSF Workshop on Universal Accessibility of Ubiquitous Computing: Providing for the Elderly*, May 22-25, 2001, Alcacer do Sal, Portugal, pp.71-74.

[4] M. Perry, A. Dowdall, L. Lines, and K. Hone, "Multimodal and ubiquitous computing systems: supporting contextual interaction for older users in the home," *IEEE Trans. Info Tech Biomed*, 8 (3), 2004, pp.258-270.

[5] D. A. Norman, "*The Psychology of everyday things'*" New York, Basic Books, 1988.

[6] B. Shneiderman, "*Leonardo's Laptop: Human Needs and the New Computing Technologies*," MIT Press, Cambridge, 2002.

[7] J. Tomlinson, M.J. Russell, and N.M. Brooke, "Integrating audio and visual information to provide highly robust speech recognition," in *Proc. IEEE ICASSP,* 1996, pp. 821-824.

[8] S.L. Oviatt, "Mutual disambiguation of recognition errors in a multimodal architecture'" in *Proc ACM Human Factors in Computing Systems (CHI'99)*, 1999, pp.576-583.

[9] A. Smith, J. Dunaway, P. Demasco, and D. Peischl, "Multimodal input for computer access and augmentative communication," in *Proc. 2nd ACM conference on Assistive Technologies*; Vancouver, Canada, 1996, pp.80-85.

[10] M.A. Grasso, D.S. Ebert, and T.W. Finin, "The Integrality of Speech in Multimodal Interfaces," *ACM Trans. Computer-Human Interaction, 5*(4), 1998, pp.303–325.

[11] S. Oviatt, "Taming recognition Errors with a Multimodal Interface," *Comms ACM, 43*(9), 2000, pp.45-51.

[12] B. Suhm, B. Myers, and A. Waibel, "Multimodal error correction for speech user interfaces," *ACM Trans. Computer-Human Interaction, 8*(1), 2001, pp. 60–98.

[13] R.A. Bolt, "Put-that-there: Voice and gesture at the graphics interface," *ACM Computer Graphics 14*, 3, 1980, pp.262–270.

[14] M. Weiser, "Some Computer Science Problems in Ubiquitous Computing," *Comms ACM*, *7*, 1993, pp.74–83.

[15] E, Kantorowitz and O. Sudarsky, "The adaptable user interface," *Comms ACM, 32*(11), 1989, pp.1352-1358.

[16] B. Shneiderman, "Direct manipulation: a step beyond programming languages," *IEEE Computer 16*(8), August 1983, pp.57-69.

[17] M. Johnston, S. Bangalore, G. Vasireddy, A. Stent, P. Ehlen, M. Walker, S. Whittaker and P. Maloor, "Match: An architecture for multimodal dialogue systems," in *Proc. 40th Ann Meeting Assoc. Computational Linguistics (ACL-2002)*, 2002, Philadelphia, Pennsylvania, USA, pp.376-383.

[18] R. Bandelloni, S. Berti, F. Paternò, "Mixed-Initiative, Trans-Modal Interface Migration," in *Proc. Mobile HCI 2004, Glasgow, September 2004, Lecture Notes Computer Science 3160*, pp.216-227, Springer Verlag.