

This item was submitted to Loughborough's Institutional Repository by the author and is made available under the following Creative Commons Licence conditions.



CC creative commons
COMMONS DEED

Attribution-NonCommercial-NoDerivs 2.5

You are free:

- to copy, distribute, display, and perform the work

Under the following conditions:

 **Attribution.** You must attribute the work in the manner specified by the author or licensor.

 **Noncommercial.** You may not use this work for commercial purposes.

 **No Derivative Works.** You may not alter, transform, or build upon this work.

- For any reuse or distribution, you must make clear to others the license terms of this work.
- Any of these conditions can be waived if you get permission from the copyright holder.

Your fair use and other rights are in no way affected by the above.

This is a human-readable summary of the [Legal Code \(the full license\)](#).

[Disclaimer](#) 

For the full text of this licence, please go to:
<http://creativecommons.org/licenses/by-nc-nd/2.5/>

Multi-Media and Process Control Interfaces: Signals or Noise?

James L. Alty
IMPACT Research Group
Dept. of Computer Science, Loughborough University
Loughborough,, Leicestershire, LE11 3TU, UK
+1509 222648, j.l.alty@lboro.ac.uk

SUMMARY Multimedia interfaces are examined and the nature of current input and output media identified. A number of design objectives for multimedia interfaces are suggested – improving efficiency, learning and providing a stimulating problem solving environment. The key problem of how to choose an appropriate medium for a particular interface situation is analysed and the concept of a Signal to Noise ratio for measuring media expressiveness is tentatively postulated. Some recent work in process control is then examined and the results interpreted from the Signal-to-Noise ratio viewpoint. These are then related to the concept of media expressiveness.

Keywords

Multimedia, Interface Design, Methodology, Empirical, Process Control.

1. INTRODUCTION

The term “multi-media interface design” came into common usage in the late 1980’s. It describes a set of techniques for facilitating the communication of information between computers and users through the exploitation of advances in computer technology. In process control applications, it is expected that multimedia interfaces will be capable of providing a wider variety of media for transferring information between operator and process (and vice-versa) than those currently employed. However, such interfaces will only be effective if a good match is obtained between the information carrying capabilities of the media chosen, the nature of the knowledge to be communicated and the requirements of the operator. Obtaining such a match is important since the multi-media approach is based upon the supposition that different media can transmit certain types of information more effectively than others and hence, if carefully chosen, can improve operator performance. Progress in utilising multimedia interface technology has been haphazard and disconnected. In many cases too much emphasis has been placed on the technology and too little emphasis on this matching problem. This paper addresses this key problem in multi-media interface design – how does an interface designer choose a particular medium to maximise operator task efficiency for particular tasks?

2. WHAT IS A MULTIMEDIA INTERFACE?

In order to communicate information to other human beings, we disturb the environment around us in such a way that those disturbances can be detected by the people with whom we wish to effect communication. The meanings of all such disturbances depends partly upon the existence of “common ground” (Clarke, 1996) between the originators and those with whom they wish to communicate, and partly upon emergent meaning during the interaction. In process control situations we can assume a great deal of common ground since the same process is familiar to both designer and operator. There will, however, always be subtle differences. It is not uncommon for operators to be familiar with operational aspects of the system of which the designers are not aware. A second issue is that of relevance (Sperber and Wilson, 1986). Information can be irrelevant because it does not present new information which is relevant to the current context, because it does not add to the existing knowledge base, or because it conflicts with the existing context and is too weak to upset it. Of course, apparent irrelevance can be used positively to support implicature (Grice, 1975) but in process control we have to assume that the designer will not knowingly use irrelevance to imply unexpressed information to the operators.

When communication takes place in the operator environment of a process plant, three special features of the communication process need to be taken into account:

- a) The existence of an intermediary (these days a computer) between the participants which is not just a transmission medium. It can transform the information and selectively make decisions about what is displayed (and how).

- b) A lack of direct user feedback to the original designer of the interactions (at least, not on-line). This means that common ground is not easily developed during the interaction, and assumptions have to be made by the designer about the operator's knowledge. To some extent, training alleviates this problem.
- c) A resulting requirement for the computer to act as a remote representative of the interface designer in all interactions at the interface.

The existence of the intermediary poses physical restrictions on the disturbances we can create. Designers are limited by factors such as the size of the screen, the quality of the sound card and some rather cumbersome input mechanisms. The lack of direct user feedback prevents designers from repairing interactions when misunderstandings arise (something that is very common in face-to-face human-human communication). The third point requires designers to allow for all reasonable variations in responses and requirements. This can only properly be done through the application of Artificial Intelligence techniques, but suitable techniques do not currently exist to do this effectively. It is not surprising that good interface design is still a difficult process.

3. HOW IS A MULTIMEDIA INTERFACE DEFINED?

Any recipient of a message has to detect a disturbance in the environment through their sensory mechanism or channel. A *channel* is a sensory channel used to communicate between human beings. Five main channels of communication – Visual, Auditory, Haptic (or touch), Taste and Olfactory – are normally used, though there are other channels such as the Kinaesthetic channel (for detecting movement).

A *medium* is an agreed mechanism for communicating information between human beings and computer systems which involves the disturbance of physical aspects of the medium itself. Any *medium*, therefore, has a set of basic tokens or symbols used in the communication process, a set of agreed structures used to arrange these symbols in different ways, and mechanisms for handling these structures. These three components are often termed the Symbols (or Lexicon), Syntax (or Structural Rules) and the Pragmatics (or Conventions) of the medium. The three properties define what valid sentences or messages can exist in the medium. The medium, *Speech*, therefore, consists of the following components:

Lexicon:	All words of the language plus other non-word sounds (ooh, ah, er, etc..)
Syntax:	The grammatical rules for combining words (not quite the same as for written language)
Pragmatics:	How we speak together, for example, taking turns, greetings etc..
Channel:	Auditory channel

Media have different capabilities for communicating certain types of information. Figure 1 shows a simple space where some properties of text (or numbers), moving video, animation and graphics are contrasted using the three axes of Qualitative-Quantitative, Real-Abstract, and Still-Animated. Numbers, are more precise than moving video or graphics. Moving video is more real than graphics and graphics are more abstract than text. Moving video and animation are highly animated

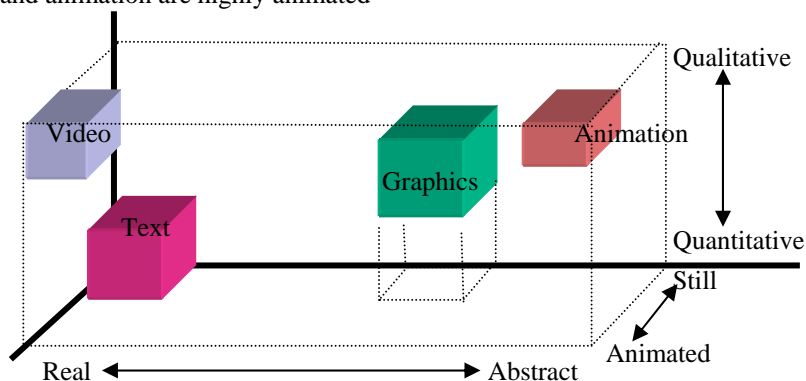


Figure 1 Example Media Space

Multi-media communication is the simultaneous (or sequential) use of more than one medium of communication to transfer information. For human beings, using multiple media is normal - spoken language, body language, gesture and touch are all used to transmit a message to another person, in parallel. The degree of success with which human beings use multiple media has convinced interface designers of the likely benefits of multimedia communication.

Interface designers employ *Input and Output Media* to communicate with users. *Output Media* must be understood by human beings, and often involve words, pictures or sounds. *Input Media* are used to communicate information to the system, and these media currently require special skills (such as typing or mouse skills) to be employed effectively. Most output media are reasonably well-matched to human capabilities since they are based upon media that have been used between human beings for many years - text, graphics, pictures, video and sound. The problems of designing effective output using these media are similar (but not the same) as those in traditional media design, for example, publishing.

Current input media are cumbersome and unnatural, requiring skills (such as keyboard or mouse skills) to be used effectively. They are also unusual in that they also need to be coupled with some form of output medium to be useful and this complicates the analysis of input media. Keyboard input is not effective unless the user receives simultaneous output of what is being typed, and a mouse requires visual feedback to be effective.

Recently, there has been interest in new types of input media. Examples include voice recognition (now beginning to reach acceptable levels of performance), gesture and pointing (where the actual visual gestures are tracked by video cameras and interpreted), eye-movement (the actual movement of the eye is tracked and used as a selection device), lip motion (to assist in speech recognition), facial expression, handwriting, and even brain wave input. Such research is driven by the current primitive state of input media in contrast to human-human communication.

4. DESIGN OBJECTIVES FOR MULTIMEDIA APPLICATION IN PROCESS CONTROL

It is important to identify the main reasons for applying multimedia design techniques in process control, because conflicts are likely to arise in possible choice of media in certain circumstances. There are three main goals in which the techniques will be applied:

- | | |
|--------------------|---|
| Efficiency | Multimedia interfaces will enable the operator to appreciate more rapidly what is happening in a dynamic system. This may result from providing representations which are better matched to operator needs. |
| Learning | Multimedia interfaces will enhance the operator's ability to assimilate what is being presented in a learning situation. |
| Stimulation | Multimedia interfaces will provide a more stimulating problem solving environment. |

All these situations are concerned with choosing the most appropriate representation to enhance problem solving. As Lieberman has pointed out "The goal of computing should be to enable collaborative problem solving between people and machines" (Lieberman 1996). Indeed one might argue that Human Computer Interaction is mainly concerned with the "design of artefacts to provide new human problem solving strengths in computer mediated domains" (Williams 1997). The representation of the artefact through the interface presents the problem-solving space, and supports navigation through this space to allow the user to achieve tasks. Thus the relationship between the representation of the problem and the user's cognitive state is an important part of this process. The design problem is the determination of this "most appropriate representation", but what may be appropriate for Efficiency may not be optimal for Learning. These three goals will be frequently referred to in subsequent discussion.

5. CHOOSING AN APPROPRIATE MEDIUM

We can assert that all appropriate representations must have at least the following properties:

- a) All the information required must be currently available (or accessible) in the representation chosen.
- b) The information should be presented in such a way as to be readily perceived and understood in the right context by the user. This means that the representation should generate, or match, some form of model in the user's head – an internal representation.
- c) Other information, not relevant to the problem solving process, should be kept to a minimum.

Designers therefore manipulate the *external representation* (that is, the set of media chosen to communicate), to make particular operator or user *tasks* as easy as possible. To do this the external representations must generate (or match with) the most effective operator *internal representation* to enable the operator or user to solve the problem.

What sort of representations might best be used? An obvious start might be to use reality. In the process control case the designer could show actual pictures of the plant and its components and (perhaps) video data of the process in action. Unfortunately, realistic representations tend to fail points a) and c). This is because most

of the information provided by realistic representations is not useful for most control purposes. A schematic diagram of a valve is usually more relevant and useful than a picture of it. Designers, therefore, tend to use representations that are more symbolic than real. However, this provides an immediate problem. Once designers move away from realistic representations, the choice of representations becomes very wide. Sometimes this may not be too difficult a choice, since there may be a set of standardised symbols for an application (Pipe and Instrumentation Diagrams in Process Plants). At other times the choice may be completely open. This therefore is the key issue in Multimedia Design – How does a designer choose a medium (or media) to represent a problem in such a way as to maximise the operator’s capability of solving it?

There are obvious examples that illustrate this point. Suppose a group of scientists wishes to examine the effects of the topology of a complex molecule on reactions which take place with other molecules. They could be presented with a listing of electron density values at all points in cartesian space. Alternatively, they could examine a 3-dimensional representation (where colour is used to show the electron density in space). In both cases, all the information is likely to be there to solve the problem. However, the listing would require hours of work, whereas the 3-D view might answer some questions almost instantaneously. Clearly, one representation is more appropriate than the other. However, no single representation will solve all communication problems. If the scientists had required exact values of the electron density at particular points then the listing would have been more appropriate.

In order to guide designers during the interface creation process, we need a measure of this “appropriateness” of fit between the design as conceived by the original designer, and its usefulness in the actual situation of use. Many words exist that might be used to describe this match, for example, “effectiveness”, “richness” or “expressiveness”.

“Effectiveness” might be measured through an examination of the use of the actual interface. We might measure the time taken to solve a problem using a particular interface representation, or measure the number and extent of external information sources accessed.

The term, “Information Richness”, has been defined by Daft and Lengel (1984) as the ability of information to change understanding in the recipient within a time interval. In their scheme, rich communications can overcome different frames of reference, whereas those low in richness are unable to overcome different perspectives (a distinction that is important in Process Control situations). The concept, which they applied to traditional areas of business communication, suggested an ordering in decreasing richness of - face-to-face interactions, telephone conversations, personal documents, impersonal written documents and numeric documents. One of the key factors identified, which contributed to this concept of Information Richness, was the existence of immediate feedback (Lengel and Daft, 1984). They suggest that communications of low richness can be effective in situations where information is uncertain (i.e. unknown but derivable), whereas rich communication is much more effective in equivocal situations (those where new data might not reduce uncertainty) (Daft and Lengel, 1986).

“Expressiveness” has been used (Williams and Alty, 1998) to describe the ability of a medium to support multiple levels of abstraction, and is therefore related to the information richness idea outlined above. From now on, therefore, we will use the term “expressiveness” for this concept.

The molecular example suggests that in trying to measure the “expressiveness” of a medium for a particular task, we are seeking to calculate something like a Signal-to-Noise ratio for *some* medium trying to meet *some* operator objective. In other words, the critical information, which needs to be communicated, is the signal and all the additional irrelevant information provided by the representation is the noise. Of course the use of a simple ratio will not capture the whole subtlety of the situation, but we hope that it might help us to focus discussion on some key issues. The calculation is not easy since the definitions of signal and noise will vary with the task, and the capabilities of the operator. It might even change over a task. One might think of it simplistically as the ratio:

$$\text{Media Signal to Noise Ratio} = \frac{\text{Essential Information.}}{\text{Total Other Information presented}}$$

In the molecule example, it is not hard to see that when the task involves overall topology, the listing provides a surfeit of “noise”, raising the value of the denominator. The real picture of a valve will also usually contribute too much noise (irrelevant details of the physical manifestation of the valve and too little required

information, such as its current open or closed state). The multimedia design problem might therefore be recast as one of maximising this Information Signal-to-Noise ratio.

One way of calculating such a ratio would be to calculate the signals and noise values theoretically. However, it is not at all obvious how this might be done – what is signal and what is noise depends upon task goals. Another, more indirect way of measuring this Signal-to-Noise ratio might be from the work required to extract the required information to solve a particular problem using the representation. This has the advantage of providing an experimental way of measuring it. This approach would be appropriate for the *Efficiency* and *Stimulation* goals identified above in section 4, but not for the *Learning* goal. In this case, a better measure might be how much knowledge is imparted, additional work being part of the learning process.

6. EVIDENCE OF MEDIA EFFECTS IN PROCESS CONTROL

In 1994, a set of process control laboratory studies was carried out as part of a large ESPRIT project (PROMISE) to probe the effects of different media in process control situations. Crossman's water bath (Crossman and Cooke, 1974) was used as the target application. The results have been re-analysed to illustrate

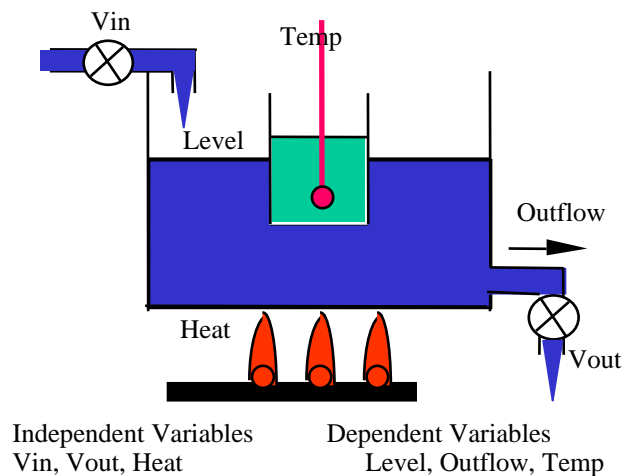


Figure 2. Crossman's Waterbath

the application of our Media Signal-to-Noise idea. Some additional results on Mental Processing Code, not reported in that paper, have also been used. The original paper is Alty *et al* (1993), to which the reader is referred for more detailed information.

Crossman's water bath is a simulated hydraulic system (see Figure 2). A bath contains water, the level of which can be altered by adding water through the in-valve (*Vin*), or increasing the *Outflow* by opening the out-valve (*Vout*). At any time there will be an outflow (*Outflow*) from the bath which could be zero if *Vout* is closed. The water in the bath is at a particular level (*Level*) which will change dynamically. The bath is heated (*Heat*). Inside the bath is a further container with a fixed amount of water in it. The temperature of the water in this vessel is continuously measured by *Temp*. Thus, changes to *Vin*, *Vout* and *Heat* cause change to *Temp*, *Level* and *Outflow*. A subject is given the system in a particular state and asked to stabilise it at a new state defined by the dependent variables (a set of limits within which these variables have to lie after stabilisation), by altering the independent variables. Subjects find the variables *Vout* and *Outflow* difficult to understand because of a coupling between *Level*, *Outflow* and the *Vout* setting. At a fixed *Vout* setting, the *Outflow* will depend upon the *Level* because the vertical pressure determines the flow. The other four variables are much easier to understand (for example, the *Vin* setting directly controls the in *Inflow*).

Fifty subjects (mainly postgraduate computing and engineering students) were given a brief introduction to the system. Both task and controls were explained to subjects but they were not told the principles of the underlying system. Each session consisted of two halves. In the first half, the subject completed 21 tasks of increasing difficulty (but all the tasks were relatively easy). In the second half, subjects completed 11, more difficult tasks, involving larger moves in the state space and narrower stabilisation limits.

Task difficulty was characterised by *compatibility*, a task descriptor defined by Sanderson *et al*, 1989 for the waterbath, which ranges from 1 (easy) to 3 (difficult). The main work measures taken during the experiment were:

The time to complete the task,
 The total number of operator actions, and
 The number of warning situations entered.

In the break between the two halves of the experiment, and at the conclusion, subjects were tested for their understanding of the state variables. Sessions were recorded on video camera, timing statistics were collected by the system and subjects were asked to verbalise their current beliefs about the system and the reasons for their actions. Sessions could be replayed. In addition, users subjectively rated the interfaces.

Medium	Description	Medium	Description
Text	Display of Single text values of each variable together with required limits	Dynamic Graph	A dynamic graph showed the recent history of all variables together with the current state. Limits were shown as boundaries towards which the graphs were heading
Scrolling Text tables	The last 20 values of all variables were displayed in a text table. Current values at the base. The table was continuously scrolled, and the limits were shown	Written	Written Text giving warnings
Graphics	A dynamic graphical representation of the water bath which reflected the current state. Current values and limits were displayed graphically.	Voice	Warning messages (Male and Female)
		Sound	The sound of flowing water which reflected the inflow rate.

Table 1 The Media used in the Experiment

A wide range of media was used to create different instances of the controlling interface. The basic media are outlined in Table 1. Firstly, there was a simple text interface. The current values of the six variables were displayed on the screen as text. The three control variables could be changed by editing the numerical values. The second interface developed this textual interface to allow operators to get a sense of variable rate of change and recent history. The last 20 values for each variable were displayed and continuously scrolled, with the current values being at the base. The third interface was a graphical mimic of the process. The water could be seen rising and falling in the tank, and the temperature rose and fell on a thermometer. Other additions included Sound (the sound of the input of water to the tank), Warnings (verbal and written) and a set of trend graphs of all the variables showing their current values, their goal ranges, and their past history.

Figure 3 illustrates how the properties of the media varied across the space defined in Figure 1. For example, the

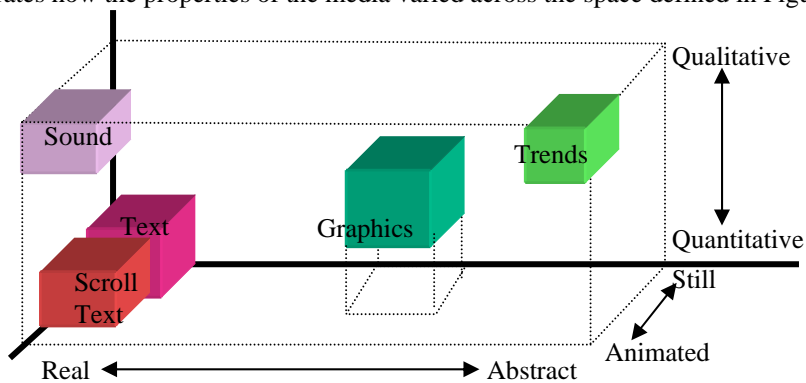


Figure 3 The Media used in the Experiment in the Space of Figure 1

Sound was very real, qualitative and dynamic. The Trend graphs were qualitative, abstract and dynamic. The scroll text was similar in many respects to the text interface but more dynamic.

6.1 EFFICIENCY AND LEARNING MEDIA EFFECTS

The effects of warnings on performance across all media presentations were collected and analysed. A warning was given by the system when any variables went outside an acceptable envelope, drawing the attention of the operator to a situation that required action. The effect on the three main variables (Time to Complete

Task, Number of Actions and Number of Warning Situations Entered is shown in Table 2. The latter variable, *Number of Warning Situations Entered*, needs some explanation. At any time, the system knows if a Warning Situation has been entered, however, it can either inform the operator or remain silent. Thus, this variable shows how many times the operators strayed outside the envelope *whether or not* they were warned. When warnings are not given, the operator may be outside the envelope but need not be aware of this fact.

Condition	Average Completion time (secs)	Average Number of Actions	Average Number of Warning Situations
Warnings	77	4.16	0.541
No Warnings	111	3.51	1.427

Table 2 Effect of Warnings on Performance

The provision of warnings improves operator performance (*Efficiency Goal*) as seen in the reduction of the completion time, and the effect is significant at the $p < 0.02$ level. This can be interpreted by inferring that the addition of the medium which provided the warnings (written or verbal messages) resulted in a better match to the operators needs. Providing warnings, therefore, resulted in an improved Signal to Noise ratio because, in this case, the warnings are an essential part of the Signal, and less work is required to solve the problem using this representation. The number of operator actions also increased when warnings were provided. One might have expected this since a warning usually triggers an action, but the result is not significant. Again, the number of warning situations entered is significantly reduced with warnings ($p < 0.02$) as one might expect, since the effect of warnings will be to encourage the operator to move back into the envelope.

However, an interesting result is obtained if the knowledge gained during the process is examined. In this case the media are being used in a *Learning Goal* situation. The results of the answers to the knowledge

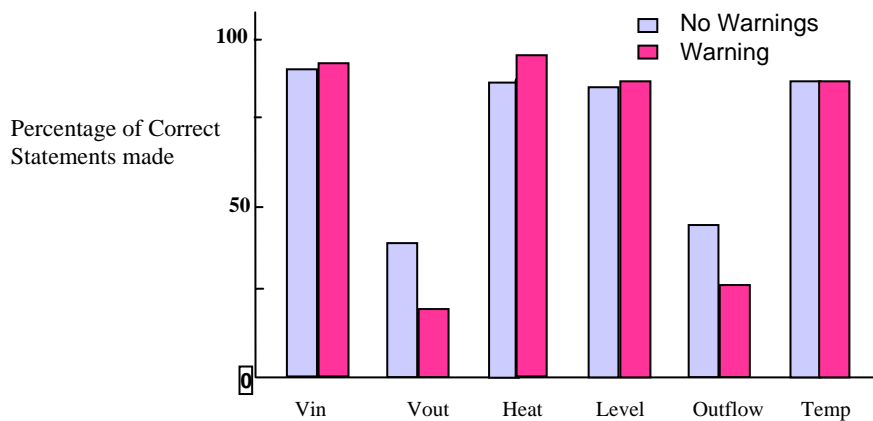


Figure 4 The Effect of Warnings on Comprehension

questionnaires are shown in figure 4. An interesting pattern can be seen. Four of the variables are well-understood independently of whether warnings are given or not; the *Vin*, *Heat*, *Level* and *Temp*. In all these cases, understanding is at or above the 90% level and there is no statistical significance in the differences between Warnings and No Warnings. Two variables, however, are poorly understood – *Vout* and *Outflow*, and the differences are highly significant for *Vout* ($p < 0.01$) and approaching significance ($p < 0.08$) for the *Outflow*.

It appears that the absence or presence of the Warnings media affected achievement in the *Learning Goals* of operators in cases where the underlying knowledge is complex. This is not a surprising result. If inexperienced operators can rely on being warned whenever they leave the envelope, they need not try to understand the underlying physics because if they accidentally leave the envelope they will be warned automatically. In the absence of warnings, the inexperienced operators have no assistance and must strive to improve their understanding of the situation. In *Learning Goal* situations, the Warnings become part of the Noise rather than the Signal.

Thus, warnings improve performance for an *Efficiency Goal* task, but inhibit performance in a *Learning Goal* task. So, if the objective of the multimedia representation is to enable the inexperienced operators to more rapidly respond to an adverse situation, then warnings are part of the information needed to solve the problem. They are part of the “Essential Information” set, so including them will increase the Signal-to-Noise ratio. On

the other hand if the main objective is to improve the learning of the inexperienced operator then the warnings become part of the noise, so including them will decrease the overall ratio.

6.2 EFFECT OF TASK COMPLEXITY ON THE MEDIA SIGNAL /NOISE RATIO

A second interesting observation from the experiments suggests how information can progressively move from the Noise to Essential Information as the task gets more complicated thereby increasing the Signal to Noise ratio.

Sound was added to the Waterbath in the form of sound of flowing water that varied with the magnitude of the *Outflow*. Sound could be provided or excluded from all the interface types (graphics, text etc.). When the measurements for completion time, actions and warning situations were compared for the inclusion (or exclusion) of sound, no significant differences were obtained as shown in Table 3.

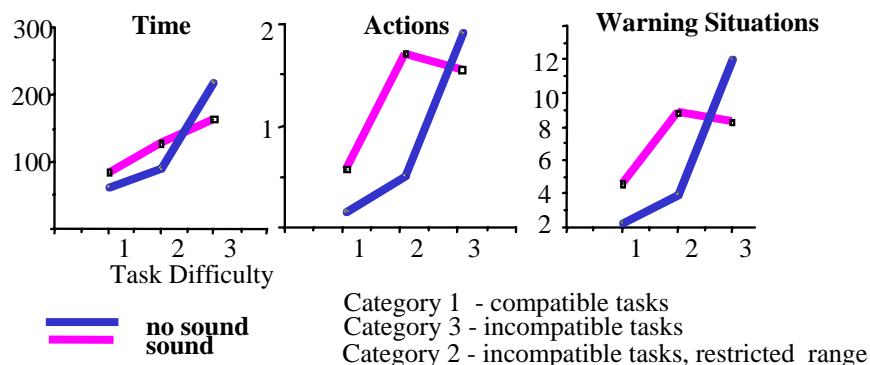
Condition	Average Completion Time (secs)	Average Number of Actions	Average Number of Warning Situations
Sound	124	6.99	0.906
No Sound	107	4.73	0.5

Table 3 The Effect of Sound

In every case the sound causes a worsening in the operator effectiveness at the interface. The time to complete the task increased, the number of actions increased and the number of warning situations entered also increased. This seems to be a very negative result for sound (or at least the way it was implemented here). However, the above results are averaged over many tasks of different complexity. Could there be an effect of sound related to the complexity of the operation being carried out?

Crossman's Waterbath has been the subject of extensive research. In particular Sanderson *et al.* (1989) have carried out an extensive analysis on the experiment and has characterised the control actions required to move from any particular state to a given goal state. The control actions are described as 1- 2- or 3- dimensional, and further subdivided as compatible or incompatible. A 1-dimensional move in Sanderson's characterisation involves the changing of one variable (say Heat) leaving the other variables free to vary. A 2-dimensional move involves the simultaneous control of two variables, and so on. She describes a "compatible" problem as one where a change in one system variable will move all others in the right direction. An "incompatible" problem is one where the change of one variable will take at least one of the other two system variables away from their goal.

For example, if the goal was to {increase the *Outflow*, increase the *Level* and decrease the *Temp*}, then opening the input valve will do all these. This is thus a compatible problem. If, on the other hand, the goal was to {increase the *Outflow*, increase the *Level* and increase the *Temp*}, then more control actions will be needed. 1-dimensional actions are always compatible. 2- and 3- dimensional actions may or may not be. It is reasonable



to assume that operators will find incompatible actions more difficult than compatible ones, and that the range of variable change required will also affect task difficulty. This provides a dimension along which we can subdivide our results. Tasks were therefore divided into the three types:

- compatible tasks (unrestricted ranges), Category 1
- incompatible tasks (unrestricted ranges), Category 2

incompatible tasks,(restricted ranges) Category 3.

The results were re-analysed on this basis and are shown in figure 5. In every case there is a reversal between categories 2 and 3. At this point sound seems to become a positive feature. None of these results have sufficient significance levels but we might postulate that the existence of the additional medium, sound, does seem to help when the tasks become more difficult.

The result can be examined in the light of our earlier Media Signal-to-Noise definition. We may postulate that at low task difficulty levels in *Efficiency Goals* activity, the sound is redundant. It does not offer information that contributes to problem solution. Its use in these situations is therefore only a contribution to noise, reducing the Signal to Noise ratio. At high task difficulty levels, the sound starts to contribute significantly to the essential information required to solve the task. Now it enhances the signal-to-noise ratio and the additional medium is therefore important in supporting the problem solving process. Thus, in *Efficiency Goal* activity, a medium may become more effective as task complexity increases.

If the user knowledge results are examined, with and without sound for categories 1 and 2, it seems to inhibit understanding of more difficult concepts (as did the warnings earlier). Figure 6 shows the results in a similar fashion to Figure 3.

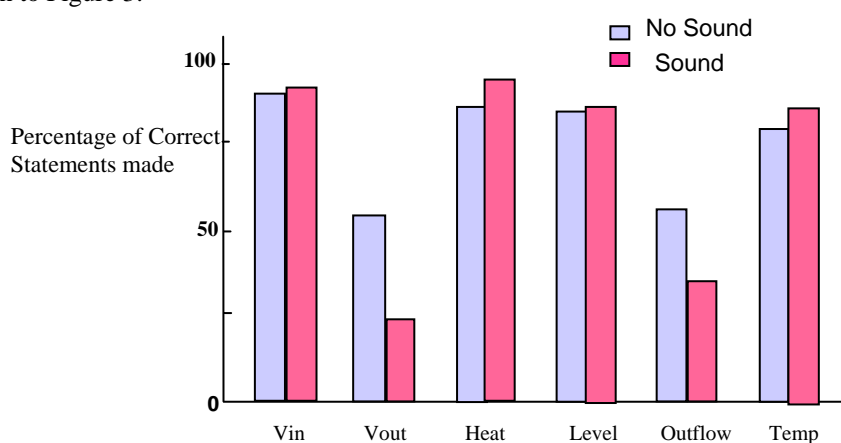


Figure 6 Knowledge Comprehension for category 1 and 2 tasks with and without Sound.

Once again, in this *Learning Goal* activity, the difficult concepts seem to be not well assimilated and adversely affected by the inclusion of sound. So although sound appears to assist in *Efficiency Goal* activity at complex task levels, it appears to inhibited learning for inexperienced operators in *Learning Goal* activities. This lack of usefulness of sound was also emphasised in subjects attitudes to sound compared with speech. All subjects rated speech above sound on all measures though only "Importance" actually achieved a significant result ($p < 0.01$).

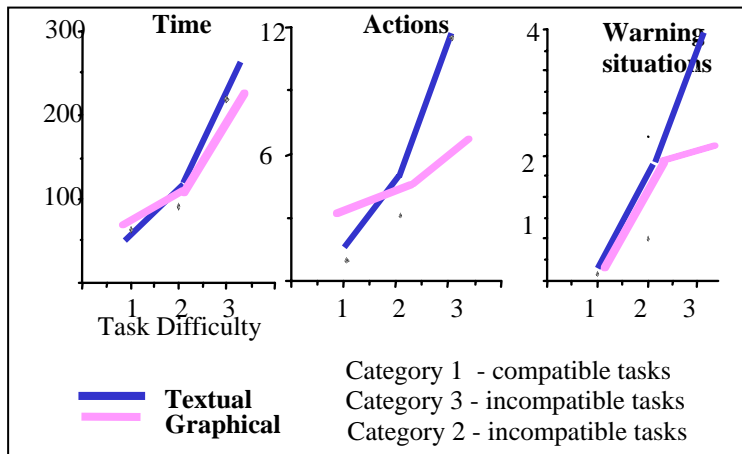
6.3 EFFECT OF MENTAL PROCESSING CODE ON THE MEDIA SIGNAL /NOISE RATIO

Finally the performance of subjects in the graphical conditions compared with the textual conditions was examined. Received wisdom would imply that subjects ought to perform better on spatial tasks when presented with information in graphical form. The independent variable being examined here is Mental Processing Code (Table 4).

Condition	Average Completion Time (secs)	Average Number of Actions	Average Number of Warning Situations
Graphical	97	4.13	0.96
textual	107	5.46	1.476

Table 4 Effect of Mental Processing Code on Performance.

The table shows that on *Efficiency Goal* activities, the Graphical Interfaces yielded better performance than the Textual ones. Only the difference in the number of actions approached significance however ($p < 0.03$). The effect of Graphical Interfaces become more interesting when one analyses the results again in terms of task difficulty. Figure 7 (similar to figure 5) illustrates this point.



The trend is significant for the Number of Actions ($p < 0.003$) and approaches significance for Warning Situations ($p < 0.03$). There is therefore an indication that the graphical interfaces are providing better information, in a more appropriate form, particularly for more complex tasks. Thus although the graphical representation might provide too much information for simple tasks, resulting in a low Signal-to-Noise ratio, as

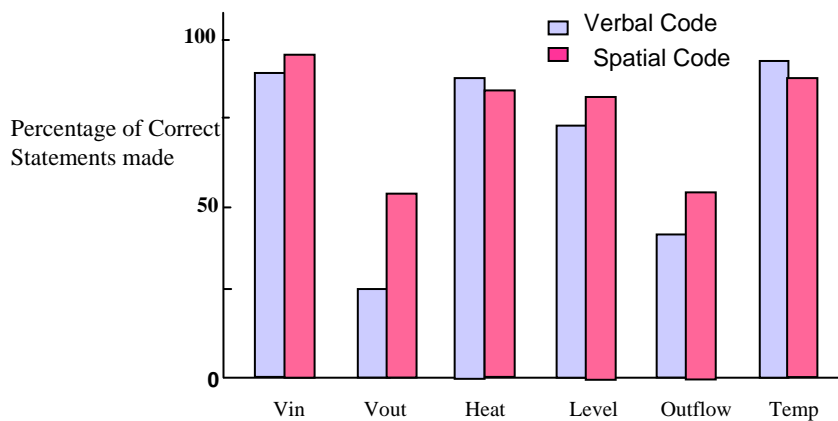


Figure 8 Comprehension and Mental Code

the task becomes more complex, the information provided becomes more relevant and essential to the task.

In contrast to sound, the knowledge results (Figure 8) showed that the Spatial Coding resulted in improved comprehension for difficult concepts such as *Vout* and the *Outflow* (significant at the 1% level for *Vout*). Thus, in this case, the Graphical Information contributes both to *Efficiency Goal* activity AND to *Learning Goal* activity.

6.4 STIMULATION AND THE MEDIA SIGNAL /NOISE RATIO

Unfortunately, the experimental data sheds little light on the effect of different media on the *Stimulation Goal*. However, the overall results from Alty et al (1994) did indicate that using multiple media in parallel had an overall significant effect on improving the understanding of complex variables in the water bath case.

One argument for using different media representations is to combat the “tunnel” effect whereby operators tend to get fixed on a particular solution path. It is argued that presenting information in a different representation can jolt the operators into a re-think of the problem. This also relates back to Daft and Lengel’s (1986) earlier point about information richness and its relationship to the support of different perspectives.

7. MEDIA EXPRESSIVENESS

Let us now return to the expressiveness idea put forward in section 7. The concept is intended to provide a measure of how well a chosen medium communicates the desired information to enable an operator or user to carry out a particular task most effectively (Williams and Alty, 1998, Williams, 1997). We have previously suggested that the concept is connected with levels of abstraction following Stenning’s work on the

representation of Euler's Circles (Stenning & Levy 88; Stenning and Oberlander, 1995). The process of abstraction is concerned with the coalescing of domain states into larger chunks, thereby reducing the complexity of the search problem [Williams, 1997]. It is clear that some media readily afford this process, others do not. The representation of button icons for activating features in WORD cannot be readily abstracted, whereas points displayed in a graph can be abstracted to higher levels such as clustering or trends. We therefore related expressiveness to this higher level abstracting ability. We call a medium that supports many levels of abstraction "highly expressive", similar to the way in which Daft and Lengel's information richness concept supports multiple perspectives.

However, the appropriate level of abstraction needed to support user problem solving will depend upon the task and the experience and expertise of the user. Thus the most effective design will occur when the expressive requirement of the user and task matches the maximum expressiveness of the medium. We say "maximum expressiveness" because it is likely that too expressive a medium could inhibit the problem solving process. In our earlier terminology, using an overly expressive medium is likely to increase the noise level and thereby reduce the signal to noise ratio.

It is easy to see how a medium can have too little expressiveness for communicating a particular problem situation (an example would be communicating a Shakespeare play in Morse Code). Flach has pointed out that a good representation needs to simultaneously represent the relevant functions, the goal states, the current state, the functional consequences of time and the critical boundaries for action for the problem (Flach, 1995). If any of these are missing or cannot be represented, then the medium is not expressive enough.

The idea that a medium can be over-expressiveness is more difficult to grasp. A medium that is maximally expressive is maximising the signal with minimum noise. Operators find graphs useful because they are often at the right level of expressiveness for many problems. A more expressive medium is natural language, but the description of a graph in natural language usually is less useful than the less expressive graphical form. Stenning, for example, has pointed out that Euler's Circle Notation is maximally expressive for solving problems with syllogisms, yet the formalism has less expressiveness than natural language. Most human beings have difficulty in dealing with syllogisms in natural language, and the Euler Notation seems to capture the problem at just the right level of complexity.

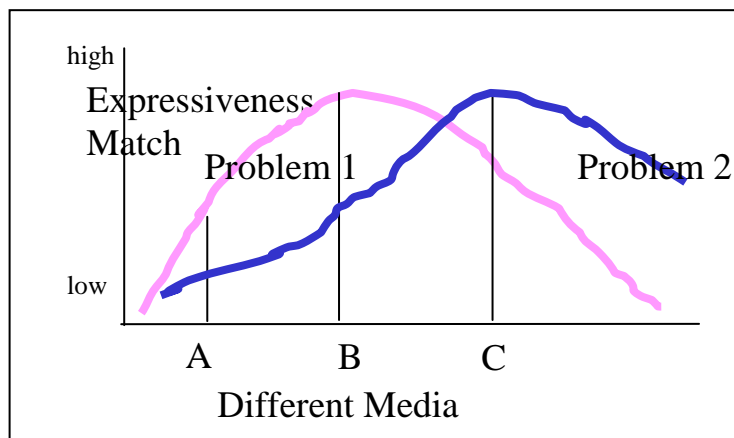


Figure 9 Media , Problems and Expressiveness

One might hypothesise that the match between the expressiveness required to solve a problem and the expressive capabilities of a medium would be as in Figure 9. Medium A does not have the expressiveness to carry information to solve either problem 1 or problem 2. Problem 1 is ideally served by Medium B, whereas Medium C is too expressive for that problem. Medium C provides an ideal environment for solving problem 2, but is over expressive for problem 1.

The Multi-media design problem is therefore is one of choosing media that are at the maximum level of expressiveness for any particular problem when our Signal-to-Noise ratio is maximised. Below the maximal expressiveness level, there is too little signal. Above it there is too much noise.

Although our minimum work measure is a good way of approaching this idea from a practical standpoint, from a theoretical perspective, much more needs to be known about how the effect of different representation abstractions can be quantified.

8. CONCLUSIONS

This paper has suggested that multimedia interfaces may assist in achieving the following goals in process control:

- Efficiency** to enable the operator to appreciate more rapidly what is happening in a dynamic system. This may result from providing representations better matched to operator needs.
- Learning** to enhance the operator's ability to assimilate what is being presented in a learning situation.
- Stimulation** to provide a more stimulating problem solving environment.

Our analysis of the experiments has indicated that there are likely to be trade-offs between these goals. For example, media that increase performance can inhibit learning. Furthermore, the usefulness of media can change with task complexity. Our sound experiments indicated that this might be the case. The inclusion of sound at low task complexity appeared to adversely affect performance, whereas it assisted performance with complex (incompatible) tasks. For all task complexity measures, sound inhibited learning.

For use of mental code (graphics or text), our analysis bears out the assertion that (for spatial tasks at least) graphical presentations appear to support performance over textual approaches particularly when the tasks become more complicated. Interestingly, our graphical interfaces supported learning as well.

We introduced the idea of expressiveness and have attempted to use the Signal-to-Noise ratio as a way of measuring a medium's capacity for supporting performance or learning. The initial results are encouraging. The ratio, whilst simplistic, did enable us to discuss the water bath results and compare media effects. The concept needs further refinement, but the initial indications are that it may be a promising line of research.

ACKNOWLEDGEMENTS

The author would like to acknowledge the work of Marius Bergan and Ciarin Dolphin who were responsible for the original detailed experimental work on which the ideas of this paper were developed. The PROMISE project was supported by the European Union under the ESPRIT scheme.

REFERENCES

- Alty J.L., Bergan, M., Dolphin, C., & Schepens, A.** (1993). Multimedia and Process Control: Some initial Experimental Results, *Computers and Graphics*, 17 (3), pp 205 – 218.
- Clark, H.H.**, (1996), *Using Language*, Cambridge University Press, UK.
- Crossman, M., and Cooke, J.E.** (1974). Manual Control of Slow Response Systems, *The Human Operator in Process Control*, (Edwards, E., and Lees, F., eds.), London, Taylor and Francis.
- Daft, R.L., and Lengel, R.H.**, (1984), Information Richness: A New Approach to Manager Information Processing and Organisational Design, In *Research and Organisational Behaviour*, Staw.B., and Cummings, L.L., (eds.), JAI Press, Greenwich, Conn. USA.
- Daft, R.L., and Lengel, L.L.**, (1986), Organisational Information Requirements, Media Richness and Structural Design, In *Management Science*, Vol. 23, No. 5, pp 554 – 570.
- Flach, J. M.** (1995), Situation Awareness: Proceed with Caution, *Human Factors*, Vol. 37, No. 1, pp 149 – 157.
- Grice, H.P.**, (1975), Logic and Conversation, In *Syntax and Semantics, 3: Speech Acts*, Cole, P., and Morgan J., (eds.), Academic Press, New York, pp 41 – 58.
- Lieberman, H.** (1996). Intelligent Graphics, In *Comms. ACM*, 39(8),pp 38-48.
- Sanderson, P.M., and Verhage, A.G., and Fuld, R.B.** (1989). State Space and Verbal Protocol Methods for Studying the Human Operator in Process Control, in *Ergonomics*, Vol. 32, No. 11, pp 1343 – 1372, 1989.
- Sperber, D., and Wilson, D.**, (1986), *Relevance: Communication and Cognition*, Basil Blackwell, Oxford, UK.
- Stenning, K., & Levy, J.** (1988). Knowledge-Rich Solutions to the Binding Problem: a Simulation of some Human Computational Mechanisms". *Journal of Knowledge Based Systems*, 1 (3), pp 143-151.
- Stenning, K., & Oberlander, K.J.** (1995). A Cognitive Theory of Graphical and Linguistic Reasoning: Logic and Implementation. *Cognitive Science*, 19 (1), pp 97-140.
- Williams, D.M.L.**, (1997), *Ph.D Thesis*, Loughborough Univ., Loughborough, UK.
- Williams, D.M.L., and Alty, J.L.** (1998), Expressiveness and Multimedia Interface Design, *Proc. of Edmedia-98*, (Ottman, T., and Tomek, I. Eds.), Freiburg, Germany, pp 1505 -1510.