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APPLYING COLOUR RESEARCH TO DISPLAYS: A FRAMEWORK

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ABSTRACT

Continuing computerisation, including that of control systems, prompts consideration of the possible benefits to human performance of colour displays. Any evaluation based on the extensive research literature on colour, however, has the problem of relating the description of laboratory tasks to that of applications tasks, since the two descriptions usually differ. A solution to the problem is proposed in the form of a flexible, extensible and potentially complete framework, which permits a re-expression of the two descriptions in a common form. The framework is described and its use is illustrated.

1. BACKGROUND

Computerisation of human-machine systems in general and control systems in particular continues at a rapid rate. In addition, recent developments in the technology have reduced the cost and increased the reliability of high-resolution colour raster displays. As a result of these two trends, colour can now be considered for most display applications both real and simulated (Huddleston 1983). These applications include a wide range of control tasks, for example: air traffic control; plant process control; and military command and control (of ships, aircraft and land-based vehicles). The advent of cheap, reliable displays suitable for many applications prompts the assessment of the possible benefits to human performance of colour. Recent reviews of colour, along with guidelines for its use in design and predictions concerning its future applications attest to the current high level of interest in colour and its use (Hopkin 1980; Silverstein 1982; Huddleston 1983; Robertson 1983; Long et al 1983).

2. PROBLEM

There exists an extensive research literature on colour and its effects on human performance (for a bibliography, see Long et al 1983). Consulting the literature is usually a preliminary to, or a substitute for, specific empirical evaluation of a system for which colour is a display option. Any assessment, however, which attempts to exploit the literature on colour coding encounters a serious problem. There is generally a mismatch between descriptions of the laboratory tasks used to assess the utility of colour and descriptions of the tasks performed by system operators, including tasks which might benefit from colour. The mismatch makes it unclear which of the effects, if any, established under laboratory conditions might be expected to transfer to a particular applications task.

The problem is illustrated as follows. Christ and Corso (1984) reported a set of laboratory experiments designed to assess the relative effectiveness of different visual codes including colour. They used three tasks, described as: 'choice reaction' (keypress to one of a stimulus set); 'search and locate' (identification of the quadrant occupied by a target stimulus); and 'identification-memory' (recall, following display off-set, of the number of target stimuli).

These descriptions of laboratory tasks can be compared with two taken from Tainsh (1982). He discusses the general requirements of displays in naval command and control systems such as submarines. In particular, he considers the roles of the 'picture compiler', who is responsible for generating on a visual display unit a tactical picture of contacts and the 'commander' who uses the display along with other information to plan appropriate manoeuvres. Typical tasks for the picture compiler include: 'associate tracks'; 'monitor collation process'; 'set up display for command use' etc. Typical tasks for the commander include: 'establish objectives'; 'initiate manoeuvre'; 'check range estimates' etc. Supposing Christ and Corso reported that colour coding advantaged 'search and locate' performance, on what basis might it be assumed that colour would either benefit a picture compiler associating tracks or a commander establishing objectives? The lack of overlap between the laboratory task and the system task descriptions obscures what they may have in common and therefore what factors - like colour coding - might be expected to affect them similarly.

What is needed to identify the overlap between the two types of task is a description common to both. The framework presented here provides this common description. The approach offered by the framework, because it is explicit and potentially complete, has advantages over implicit, more intuitive mappings between the tasks, based only on experience of the applications domain and a reading of the research literature. First, because the applications task descriptions are explicit, they can be compared in detail with specific studies rather than with just an overall view derived from the literature. Second, because the descriptions are explicit, the framework permits the identification of specific mismatches in the case of partial overlap. Third, because the framework describes both the research and the applications domain, it constitutes a de facto structuring of research for the purpose of application.

3. FRAMEWORK

One way to obtain descriptions in a common form would be to re-express the laboratory tasks in terms of the application tasks. An alternative solution would be to re-express the application tasks in terms of the laboratory tasks. Unfortunately, the first tends to produce only a high level description, and the second only a low level one. The solution offered here attempts to provide a description at an intermediate level by re-expressing both types of task in terms of a common framework. The common description means the overlap between them can be identified. The greater the overlap, the more it might be reasonable to expect the effects established for the laboratory task to transfer to the applications task. A description of the framework follows.

The framework consists of two kinds of descriptors - 'entities' and 'functions'. Functions characterise the 'doing' of an action (like a verb); and the entities characterise that to which the action is done, that is an object (like a noun). Actions are described as a function-entity pair; tasks are described as sets of function-entity pairs. Entities and functions are organised differently within the framework.

Entities

The framework assumes the existence of a 'universe' which is made up of 'entities'. An entity is described at different levels of detail. An entity at one level is redescribed in more detail at a lower level. The rule of redescription can be thought of as: 'is made up of', or: 'can be rewritten as'. There are two types of domain within the universe: the display world domain and the real world domain. In general, entitites in the display world domain symbolize or represent entities in the real world domain. Since the present paper is concerned only with the display entities, no further reference will be made to the real world entities.

'Features' are the lowest form of entity. They constitute elements or primitives of the domains. Examples of features from laboratory and applications tasks are: dots; circle segments; straight line segments etc. Taken by themselves features have little direct relevance to tasks.

Features are redescribed at a higher level as an 'object'. Objects are, in general, those entities which are made up of the smallest combination of features which have some meaning in the task. Examples of display objects include: icon; number; track; axis etc. An axis is redescribed at a lower featural level as a set of straight line segments.

Objects themselves are redescribed at a higher level as a 'sub-group'. Examples of sub-groups are: graph axes (that is at least two); number strings; contacts etc. A contact sub-group is redescribed as a set of objects: track, number, label etc. An object (for example, track) is redescribed as a set of features (line segments).

Sub-groups in turn are redescribed at a higher level as a 'group'. Examples of groups are: types of string (alpha versus numeric); classes of contact (friendly versus hostile); types of alarm icon (urgent versus normal) etc. A group of symbol strings can be redescribed as a set of sub-groups (number strings) and in turn objects (numbers) and features (straight line segments).

This organisation of entities within the framework has a number of important properties. First, the framework is flexible in that only the levels required by a particular description need be considered. The remaining levels can be ignored. Second, it is extensible in that it can accommodate any number of levels. If required, sub-groups can be redescribed as sub-sub-groups, sub-sub-groups as sub-sub-sub- groups, and so on. Thus it can be used to describe displays of any complexity. In this way, it is able to provide a potentially complete description. Third, the levels of the framework are relative. Levels are ordered relative to one another following the rule of re-description. If required, the assignment level between the entity structure and the display can be changed. Once the assignment has been made, however, the levels become relative to it. The utility of the organisation of entities, then, lies both in its levels of assignment to a particular display and the relative levels of description within the display.

Functions

The entities just described are complemented within the framework by 'functions'. These reflect the 'doing' aspects of an activity. There are four functions in all: 'separate'; 'select'; 'classify'; and 'change'. These four functions were chosen because they were found adequate to describe a complex set of command and control tasks (Long et al 1983). The functions are used in one of two modes. In 'perceptual' mode, the display is assumed to be present and in 'memorial' mode, absent. The only difference is whether the relevant information is available to the operator. To simplify the description of functions (for reasons of space) only perceptual mode will be considered here. Functions, however, operate equally in memorial mode for both the display and the real world domains. Functions operate at all levels of the entity framework. 'Select-object' and 'select-group' are both allowable descriptions.

'Separate' has the consequence that an entity on a display becomes differentiated either with respect to other entities or to its background. The entity, then, has an existence of its own. The entity, however, has no identity either as an individual entity or as a member of a class of entities. For example, 'separate-object' describes the differentiation of a symbol - either from its background or from other symbols. Separate can be used with any entity. For example, 'separate-group' would describe the differentiation of a set of icons or of a set of contacts.

The second function 'select' has the consequence that an entity on a display becomes available for incorporation into performance of a particular task. It assumes that entities have existential status, that is the select function presupposes the separate function. Once an entity is in the state of having been selected, it becomes available for further task requirements. For example, if the concern is with a pair of letter strings, rather than with the remaining strings, then 'select-sub-group' would describe only those two objects together as relevant for the task. The remaining sub-groups would be considered irrelevant, unless and until they were selected.

The third function 'classify' has the consequence that an entity acquires either individual or class identity. Identity is assumed to be required for task performance. Classify, then, presupposes select (which in turn presupposes separate). 'Classify-object' describes the assignment of a symbol to an individual identity, for example, B, or to a class identity, for example, letter. 'Classify-sub-group' would describe assignment to ABC or letter string.

The fourth and last function 'change' has the consequence that the state of an entity becomes different. The state may be modified - for example, 'change-sub-group' would describe the substitution of one set of contact labels for another. The entity may also be removed. For example, 'change-object' would describe the deletion of a label. 'Change-object' would also describe the creation of a new entity by the addition of a label. Decision-making tasks in particular require the use of the change function for an adequate description.

Change presupposes classify, which presupposes select, which in turn presupposes separate.

The selection and organisation of the functions has important properties similar to those of the entities. First, the organisation is flexible in that only the functions required by a particular description need be considered. Second, the set of functions is extensible. Other functions could be added, if this was considered necessary in any particular instance to provide an adequate task description. Extensibility ensures the potential completeness of any task description. If required, the assignment level between the functions and the display can be changed. However, once the assignment has been made, the ordering of the functions becomes relative according to the relations of presupposition.

In concluding the description of the framework, any activity - laboratory or applications - can in principle be completely described as a set of function-entity pairs. For example, if an operator is monitoring a display for labels (objects) incorrectly assigned to contacts (sub-groups) and modifying them, the description might be:

separate - sub-group	(from other contacts)
separate - object	(from other labels)
select - object	(for further action)
classify - object	(as incorrect label)
change - object	(to correct label)

Alternatively, the operator scanning the display for something unusual might be described as repeated sequences of: 'separate select -classify' with the appropriate level of entity.

In summary, then, the framework of entities and functions permits a potentially complete description of applications and research tasks in a common language, so enabling an assessment of whether findings are likely to generalise outside the laboratory. An illustration of the use of the framework follows.

4. APPLICATION TO THE FRAMEWORK

Using the framework requires the following procedures: (i) select the applications activity to be assessed for the possible benefits of colour; (ii) use the framework to derive a description in terms of function-entity pairs; (iii) use the functions in the description to interrogate the research literature; (iv) identify a relevant study, that is one having a comparable use of functions, perhaps including the highest level involved in the applications task; this requires a partial description of the applications task; (v) use the framework to complete the description of the research task; (vi) compare the applications and research descriptions;

(vii) assess the likely transfer of the research findings to the applications task on the basis of the overlap between the descriptions.

The application of the framework is illustrated using a hypothetical task taken from Tainsh (1984), cited earlier, and comparing it with research reported by Cahill and Carter (1976) using a visual search task. Suppose a component of the picture compiler's task is to inform the commander on request of the movements (approaching or withdrawing) of particular vessels (hostile or friendly) and the concern is to assess the potential of colour coding to facilitate performance of the task. For the purposes of the example: (i) the compiler is assumed to have been asked by the commander whether a particular enemy frigate is changing direction; (ii) there are both hostile and friendly contacts represented on the display; and (iii) hostile and friendly contacts are coded in different colours. For clarity of exposition, entities are referenced in brackets. The appropriate description of the task in function-entity pairs follows:

separate - group	(hostile contacts from others)
select - group	(for further action)
classify - group	(as hostile)
separate - sub-group	(one contact from hostile contacts)
select - sub-group	(for further action)
classify - sub-group	(as frigate)
separate - object	(track from labels etc)
select - object	(for further action)
classify - object	(as approach)

Consider now a research task which might have implications concerning the utility of colour for the applications example cited. The highest level function in the description is classify, used in conjunction with a number of different entities. A study reported by Cahill and Carter (1976) seems to be appropriate, which showed that colour can be used to aid performance. They provided the subjects with two digits from a random three digit string (sub-group) and asked them to report the third (object). The subjects were also provided with the colour code of the designated item - a code shared with some items (group), but not all items. To perform the task, the subjects used the two initial digits (42) and the colour to locate the designated string (426) and to report the final digit (6). Two variables were manipulated: the number of items in the display and the size of the colour code. In general, the results showed that search times <u>increased</u> as the display size increased but <u>decreased</u> as colour code size increased from 1-5. Assuming the subject is searching for a red coded target string among other coloured strings, the appropriate description of the task in terms of the framework might be:

separate - group (red digit strings from others)

select - group	(for further action)
classify - group	(as red)
separate - sub-group	(one digit string from red digit string)
select - sub-group	(for further action)
classify - sub-group	(as 426)
separate - object	(6 from 42)
select - object	(for further action)
classify - object	(as 6)

If the description of the research task is compared to the description of the picture compiler's task, it will be seen that they overlap both in terms of the entities and of the functions. If the compiler's display, then, is coded as assumed in the example, the overlap in the descriptions would provide reason to believe that the effects reported by Cahill and Carter (1976) would transfer to the compiler's task. Colour, then, would be expected to aid performance and in the particular way identified.

5. CONCLUDING COMMENTS

This paper has identified, in the particular context of colour, the general problem of applying research findings from laboratory tasks to applications tasks. In addition, the paper has proposed a framework within which both research and applications tasks can be described and has illustrated the use of the framework. A more complete exposure of the framework would require more extended illustration across a wider range of research and application tasks. To this end, a more complete version of this paper is currently being prepared (Long et al in preparation).

There are, however, a residual set of problems which cannot be discussed here in any detail. In all cases, however, the framework suggests how the problems might be approached. For example, procedures are required which apply when there is only partial overlap between the description of the research task and that of the applications task. In this case, the literature could be re-sampled and the framework reapplied. Another problem concerns the integration of findings from different laboratory tasks, all of which might be shown to be relevant by the framework. In this case, the framework could be recruited to re-interrogate the literature. Last, there is a need to make explicit the relations between applying laboratory based research knowledge in general and information on colour in particular. The framework suggests that colour is only a special case of the more general one. These points will also be discussed fully in Long et al (in preparation).

In summary, however, the framework fulfills a real need. It provides a flexible, extensible and potentially complete organisation, which permits a re-expression of applications and laboratory tasks in a common form, so permitting an assessment of the possible benefits of colour to human performance based on the existing research literature.

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TOUCH-SCREENS: A SUMMARY REPORT OF AN EVALUATION OF IMPROVED SCREEN LAYOUT DESIGNS

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The optimization of touch-screen switch displays, for use in function selection input tasks, was approached from the point of view of enhancing visual search performance when searching for a key. Three proposed screen layout designs had previously been developed for this purpose. They were intended to structure key search by the association of keys to performance cue features such as colour coding, semantically grouped key blocks and spatially separated/defined key blocks. These three principal cue feature designs were evaluated under an experimental simulation of a function selection task. Additionally subsidiary cue feature effects, such as those of key position information and key to code association strength, were examined.

The results indicated that among the principal cue features, only semantic grouping represented an improvement over a non-organised design acting as a control. Further, the combination of principal and subsidiary cue features within any one design layout was seen to have modified its effectiveness as a visual search performance aid. In particular, a knowledge of key position was seen to have been rapidly acquired and facilitated key search. Also, stronger associations between keys and cue features were seen to have enhanced their facilitative effect on performance. Recommendations are made concerning the use of visual search cues for the optimization of touch-screen displays.

INTRODUCTION

Many modern computer systems provide a set of pre-programmed function options amongst which the user may select. These function alternatives have typically been