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Improving discrimination of symbols for display at low resolution

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SUMMARY

This research draws attention to the fact that the issues involved in rendering characters on screen at low resolution are as relevant to symbols or icons as they are to letterforms. The results of research aimed at improving the perceptibility of letterforms on screen are used to develop a set of modifications that can be applied to symbols that have been scanned from an original design on paper. These modifications are implemented in two stages: rule-based modifications, followed by individual pixel editing. The effectiveness of these modifications in improving the discriminability of symbols varying in graphic complexity is evaluated by a perceptual experiment which compares the unmodified versions with the two modified versions. Subjective judgements of each of the versions are also obtained. The results suggest that these modifications can improve the discrimination of symbols on screen. However, the graphic complexity of symbols affects the type and extent of modifications that can be made. This factor must therefore be considered in any development of automatic instructions for the rendering of symbols at low resolution.

KEY WORDS Symbols Perception Screen Hinting

1 INTRODUCTION

As the problems of low resolution displays have been recognised, techniques have been developed to avoid or rectify some of the difficulties. But, as with general legibility research [1–9], most attention has been directed at letterforms, rather than symbols or icons. However, the difficulties of displaying icons on low resolution displays have been recognised [10,11], if not systematically explored.

The look of low resolution forms is determined not just by technology or limitations on image processing (e.g. sampling rate), but also by our visual system. The type of question that has been asked in relation to digital letterforms is what is the lowest resolution that can still produce recognisable letters [12]. The discriminability of characters of a typeface is therefore measured. Discriminability relates to the differences between individual forms and is highly relevant to the perception of symbols. Icons are very often selected by a user from a group of icons which may share some features. Although users learn to attach meanings to icons, differences in their graphic forms can facilitate such learning, making it easier to distinguish one icon from another.

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Some argue that the shapes of characters should be designed specifically for the medium [13,14], and in designing icons, certain complex lines and shapes should be avoided at low resolutions [10]. However, symbols are not restricted to a specific character set (*cf*. ASCII) which can be designed or re-designed for the screen. Some icons are designed with regard to the resolution of the screen, but symbols designed to be printed on paper may also be digitised for use on screen.

Converting from an analogue form to a bitmap representation at a low resolution introduces problems that have been addressed in relation to the production of bitmap characters from outline descriptions [15–17]. Modifications are necessary to improve perceptibility. The most efficient method to restore a degraded image is to develop software which automatically implements modifications. This has been achieved with letterforms through instructions [18], grid constraints or hints [19].

Defining the type of modifications to apply to specific parts of characters is only possible if the elements of the characters have been identified. Symbols have not been systematically divided into elements and the range of variation in the basic form of symbols may prohibit any attempt to agree upon a standard set of elements. However, symbols may share some elements of letterforms which would suggest the type of modifications that could be applied to them.

This research proposes some elements of symbols as candidates for modification by combining knowledge of the graphic characteristics of symbols with the type of modifications made to letterforms. The modifications that may be relevant to symbols have been adapted from [18], but are consistent with other research [19]. The rules, as applied to symbols, can be simply defined as:

- correct the width of lines (which can become thicker or thinner in scanning) and make all lines which should be of equal width the same width
- make horizontal and verticals true to the original (removing jaggies)
- correct, then ‘copy and paste’, repeated or symmetrical elements
- replace regular shapes by object-oriented graphics (e.g. circles, triangles)

These rule-based modifications do not necessarily account for all the noise produced by digitisation. Automatic modifications should be followed by hand tuning of pixels when using low resolutions [18]. Any remaining variation from the original must therefore be corrected in a second stage in which pixels are added or removed.

This research examines the perceptual effects of these two stages of modifications in a discrimination task. The task does not aim to simulate the way in which users identify and select an icon when using a graphical user interface. The experiment is designed to examine graphic features that may contribute to the discrimination of symbols.

Most experimental research on symbols has focused on cognitive issues relating to meaning, rather than looking at perceptual factors. This may be because people tend to naturally impose some sort of meaning upon such stimuli, but may also be due to the difficulty of identifying, defining and controlling the graphic elements of symbols. This variation in graphic form must be considered in relation to the modifications.

Previous experiments on the discrimination of symbols on screen have demonstrated perceptual differences between graphically simple and complex symbols that had been classified according to users’ subjective judgements [20]. This study therefore investigates whether the modifications that have been adapted from those applied to letterforms can

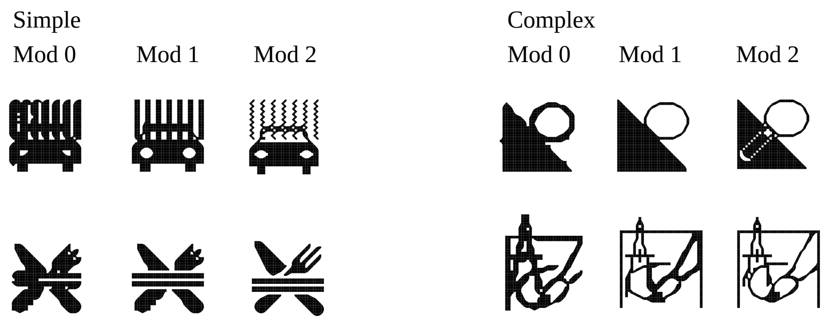

Figure 1. Four examples of symbols at different stages of modification

improve the discriminability of graphically simple and graphically complex symbols displayed at low resolution. Subjective judgements are then used to further explore the issues of discrimination and identification.

2 METHOD

Sets of four symbols were selected from a variety of sources including Isotype, Blissymbolics, Olympic symbols, meteorological symbols and Apple Macintosh icons. The four symbols making up a set were chosen to be maximally similar to each other to make the discrimination task relatively hard. Graphically simple and complex symbols were selected according to the judgements of an independent group of subjects.

Symbols on paper were scanned into the computer and saved without any editing. These symbols formed the group labelled 'Mod 0'. The rule-based modifications were then systematically applied to copies of these symbols to form the group labelled 'Mod 1'. The editing was carried out using SuperPaint, which provides tools for both bitmap editing and object-oriented manipulations. Those shapes that could be defined geometrically were converted from bitmap to object to regularise the shapes. Where appropriate, straight lines were made horizontal or vertical, and the widths of lines were adjusted to reflect their original values, and to maintain a consistent thickness. Repeated elements were copied and pasted to ensure consistency. Copies of Mod 1 symbols were then edited according to the second stage of modifications and the group was labelled 'Mod 2'. These modifications involved individual pixel editing with particular attention given to curves and fine details. Space was created between objects that had merged. Examples of symbols at different stages of modification are given in Figure 1. With some symbols, modifications could not be applied at both stages.

The experiment was run on an Apple Macintosh Plus computer with a standard size screen for this model, measuring 9 inches across the diagonal, and with a resolution of 72 dpi. All symbols were a size that fitted within a square of 32 by 32 dots (approximately 1.25 cm^2), the size of symbol commonly displayed on 72 dpi screens in the form of Macintosh icons.

Subjects were shown two symbols, one following the other, and were required to say whether they were the same or different. The first symbol was displayed for approximately

133 msec (durations were measured in 1/60 sec), followed by a mask of about 2133 msec, followed by the second symbol, again lasting approximately 133 msec. Each symbol could occur in any one of ten positions on the screen. Trials could consist of two symbols at the same stage of modification (same Mod conditions) or a mixture of modification stages (different Mod conditions). The order of modification stages within a trial was randomised.

Subjects responded using a rating scale which varied from ‘sure same’ through ‘same’ to ‘different’ and ‘sure different’. If the trial contained two different symbols, the second symbol was one of the other three symbols of the set. Subjects were not required to attach any meaning to the symbols, but they may automatically have attempted to do so. Although some of the symbols would have been easier to name than others, this variable was not confounded with stage of modification and therefore could not account for the results.

A discrimination index was computed for each subject using a non-parametric assessment of the area under the ROC curve, $p(A)$. The discrimination index was transformed by $2\,\mathrm{arcsin}\,/p(A)$ into a form suitable for statistical analysis [21]. Analysis of variance was carried out on the transformed scores.

Subjects were volunteers from the student population who were paid to participate in the experiment. They came from a variety of disciplines and were likely to have a range of experience in using graphical user interfaces. Their experience was therefore a random factor. Sixteen subjects each completed 360 trials and the order of trials was randomised across all conditions. Modification and symbol group were both within subject variables.

3 RESULTS

The data from the different Mod conditions were analysed in terms of the modification applied to the first symbol. For example, Mod 0 with Mod 1 trials and Mod 0 with Mod 2 trials were combined.

Analysis of variance showed a main effect of complexity $(F(1{,}15) = 55.16, p < 0.01)$ where graphically simple symbols were better discriminated than graphically complex symbols. The difference between the type of Mod condition was also significant $(F(1{,}15) = 34.11,\ p < 0.01)$: same Mod conditions were easier than different Mod conditions. There was a significant interaction between graphic complexity and type of Mod condition $(F(1{,}15) = 4.82,\ p < 0.05)$. These data are illustrated in Figure 2.

In the same Mod conditions, there were no significant differences between stages 0, 1, and 2 which would be clear support for an improvement in discrimination due to modifications. However, the better level of performance in the same Mod conditions when compared with different Mod conditions does suggest that there are perceptual differences between the stages of modification. In order to explore these differences further, the data from the different Mod conditions alone were re-analysed to look at the difference between the two stages of modification within a trial. For example, trials where Mod 0 was followed by Mod 1 were combined with Mod 1 followed by Mod 0 trials to form one condition.

Analysis of variance produced main effects of complexity $(F(1{,}15) = 39.82, p < 0.01)$ and stages of modification $(F(2{,}30) = 4.69, p < 0.025)$. Figure 3 shows the three different Mod conditions for graphically simple and complex symbol sets. With simple symbols, discrimination was significantly better with the combination of Mods 1 and 2 than with Mods 0 and 2. The pattern was different with graphically complex symbols, where Mods 0 and 1 were significantly better than Mods 0 and 2.

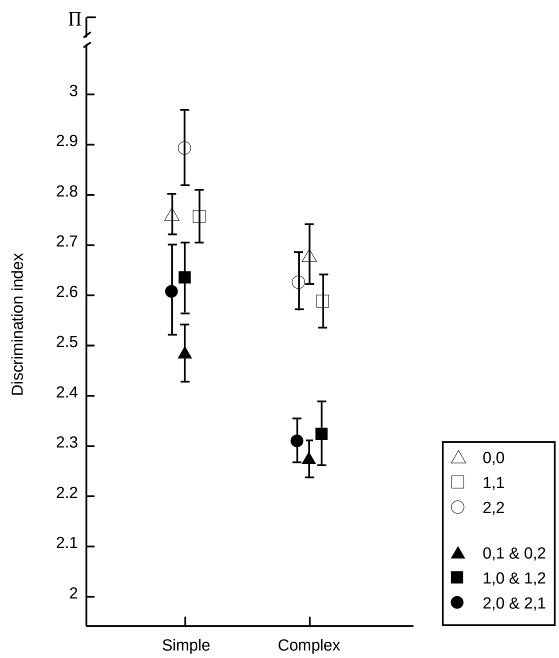

Figure 2. The effect of different stages of modification on graphically simple and graphically complex symbols

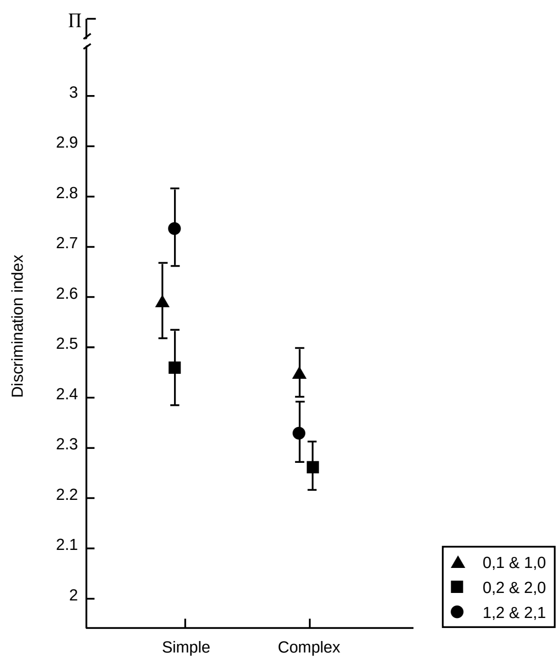

Figure 3. The effect of different stages of modification with the different Mod conditions grouped according to the difference between modifications

4 DISCUSSION

The higher level of performance with graphically simple symbols compared with graphically complex symbols is consistent with previous experiments [20,22,23]. However, the effects of modification are different for simple and complex symbols.

There is no clear evidence for the advantage of modified symbols over unmodified symbols. However, discrimination is easier when the two symbols within a trial are at the same stage of modification. This suggests that a better level of performance will be found when there is greater perceptual similarity between symbols within the trial. For graphically simple symbols, the higher level of discrimination of the mixture of Mods 1 and 2 suggests that Mods 1 and 2 may be perceptually quite similar. With graphically complex symbols, however, symbols with stage 1 modifications may be more similar to unmodified symbols, as this combination produces better performance than the mixture of Mods 1 and 2.

Although these results support the existence of perceptual differences between symbols at various stages of modification, it is important to know how these modifications affect the perceptibility of symbols.

5 FURTHER INVESTIGATION

We therefore continued by investigating two related aspects of symbol perception, *discrimination* and *identification*, in a different type of task. Subjective judgements were elicited to establish what effect people thought the modifications had on the similarity of symbols within a set (discrimination) and similarity to the original (identification).

It is important to ask both these questions, as the discriminability of items within a set may be improved, but the symbol may then look less like the original symbol and there may be problems with identification. Discrimination and identification are both important factors in the perception of letterforms on screen. However, with letterforms, a distinction can be made between identifying the individual characters and identifying the typeface. When typefaces are rendered on screen at small sizes, changes to letterforms can be made which improve both the discrimination of individual characters and their identification, but the typeface may not be identifiable, possibly as a result of the changes. Whilst being unable to identify a typeface may not be a problem, it is important to be able to identify a symbol, in the same way that it is important to be able to identify an individual character.

5.1 Discrimination task

Subjects were asked to compare symbols within sets and to rank the sets from the one which contained symbols most similar to each other to the one which contained symbols least similar to each other. Four variants of each set were compared, each containing the same four symbols. The variants corresponded to the different stages of modification: the three stages of modification (Mod 0, Mod 1, Mod 2) plus the original symbols before they had been scanned.

The forty symbol sets used in the previous experiment were divided in two and ranked by twelve subjects. All variants were presented on paper, which made it easier to make visual judgements. The translation from screen to paper is not a problem as, at this stage, we were interested in the relative differences between modifications, not absolute measures.

Subjects' rankings of the four variants of twenty sets from most similar to least similar were combined to produce a total score for each subject. Kendall's Coefficient of Concordance (W) was used to measure the degree of agreement between the twelve subjects. This produced a correlation of 0.969, $(c2 = 34.884, p < 0.01)$. There was significant agreement that Mod 0 sets of symbols were most similar to each other (most difficult to discriminate), Mod 1 were less similar, Mod 2 were even less similar and the originals were least similar to each other (the easiest to discriminate).

5.2 Identification task

A different group of subjects was asked to compare three variants of a symbol with the original symbol and place them in order of similarity to the original. The three symbols were Mod 0, Mod 1 and Mod 2 variants of the same symbol.

Symbols were taken out of their sets and the variants were compared individually, which generated 160 comparisons (forty symbol sets with four symbols per set). These were arbitrarily divided into four groups and a total of twenty subjects (five per group) each completed forty rankings. Symbols were presented on paper, with the original on card to distinguish it from the other three symbols.

For each of the four groups of subjects, the rankings of individual subjects were totalled across the forty symbols. It was unnecessary to test the correlation between subjects as there was perfect agreement. Mod 0 symbols were judged as least like the originals, Mod 1 symbols were closer to the originals, and Mod 2 were most like the originals.

6 GENERAL DISCUSSION

The discrimination and identification judgements confirm that the proposed sets of modifications, when applied to symbols, increase the differences between symbols in the set and increase the similarity of symbols to the original. However, graphic complexity affects the type and extent of modifications that can be made to improve the discrimination of symbols.

Graphically simple symbols are more suited to rule-based (stage 1) modifications, which deal with geometric elements, and these symbols may not require further detailed editing. In this study, graphically simple symbols were generally made up of a relatively small number of geometric elements, or repeated elements; they typically had fewer changes of direction in the outline than graphically complex symbols, and appeared less dense.

However, graphically complex symbols may be unsuitable for automatic modifications as it may not be possible to significantly modify them following a set of rules. Symbols in this category generally contained more different elements, which were less regular, with more changes in the direction of the outline. These details require hand tuning to improve discriminability and in such cases, individual pixel editing (stage 2) makes the difference.

The modifications applied to symbols in this paper drew upon research into the techniques used to improve the discrimination of letterforms. In defining the type of modifications to apply to specific parts of letterforms, it was first necessary to identify the elements of the letterforms. Although the labels for parts of letterforms may vary, there is some agreement as to what should be described [24,25].

Symbols have not been treated in the same systematic way. However, although symbols are extremely varied in their overall graphic form, an analysis of the components suggests that a reasonably large set of symbols can be described in terms of some basic elements. Published collections of symbols have proposed a number of graphic forms to categorise individual symbols. The elements may be a few basic forms, such as curves, straight lines, and dots [26], or slightly more extensive, including circles, squares, triangles, points, lines and curves [27]. A more complex set of graphic forms [28], consisting of sixteen categories, builds upon the more basic forms to include categories of arrows, people and animals. This last type of classification may be useful in ordering and grouping symbols, but is less relevant to the current graphic analysis. In order to explore the extent to which these modifications are applicable to symbols in general, basic elements need to be identified.

Other techniques may exist for modifying graphic forms that have undergone various transformations. However, some of the graphic elements of symbols that have been identified are also elements of letterforms, which supports the application of methods used with letterforms to symbols. Furthermore, the rule-based modifications can be applied to these basic elements (straight lines, circles, triangles) and may therefore form the basis for improving the discrimination of a large range of symbols.

7 CONCLUSIONS

Simple symbols, composed of basic geometric elements, can be modified by a rule-based system. Graphically complex symbols require individual pixel editing, but in some cases, rule-based modifications can also be applied. The results of this study suggest that these modifications improve the discriminability of symbols. However, to clearly demonstrate such improvements, a more sensitive perceptual task may be required, or a larger range of symbols.

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