MAN-MACHINE INTERFACE DESIGN BASIS DOCUMENT:

INFORMATION CODING FOR COMPUTER DISPLAY SYSTEMS

REV. 0

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2.0 Introduction

This document, sponsored by the Control Room and Computer Development group of the Strategic Operations Division, presents Human Factors criteria for the development of information coding schemes in computer display systems.

Information display systems should support a quick and accurate transfer of information to the user. Coding information is one technique available to the designer to meet this goal.

Coding methods should be incorporated when any of the following three conditions are applicable:

- when a dense presentation of information is required
- when the task requirements are difficult or precise
- when a quick response time is essential

Coding techniques should be viewed as one option among many to facilitate information processing and interpretation. The arrangement of the information and the mode of presentation will have dramatic impacts on information transfer. One cannot incorporate coding into badly formatted displays and expect dramatic operational improvements. Therefore, coding should be one of the last elements display design - the best format should be developed for presenting the information to the operator prior to including the coding features.

Characteristics of a Good Code

- Detectability - Any stimulus used in the coding of information must be detectable or perceivable by the user.
- Discriminability (1) The user must be able to discriminate between different coding techniques; (2) within a given coding modality, the user must be able to discriminate different values or states. The number of discriminable stimuli within a coding dimension changes across dimensions and of the type of task - either a relative or an absolute discrimination.

A person's ability to detect differences between stimuli (to make a relative judgement) is much keener than one's ability to detect a difference with a remembered comparison. Introducing reference points such as perceptual anchors can increase the effective resolution within a coding class by allowing relative judgements.

- Compatibility - The code chosen should be compatible with the type of data or information being coded. Thus a qualitive code (symbols, color) should be used for qualitive data; a quantitative coding technique (length, intensity, size) is better for presenting quantitative information.

  For example, color could be used to code a quantitative dimension such as temperature as in an infrared photograph. This is a good way to represent differences in temperature. However, this is a poor way to indicate temperature values since there is no obvious relationship between color and quantity. When the value of a data point represented by green doubles, what color should result?

- Association - Symbol codes should physically represent the actual object being portrayed.

- Standardization - The use of codes should be standardized throughout the display system and the surrounding user work station. If red is used as an alarm color in the indicator lights about the control station, red should also be reserved as an alarm color on the CRT displays if at all possible.

- Redundancy - It is advantageous to use redundant coding: two or more coding dimensions are used in combination to designate a particular condition.
- In addition, a code should not introduce fatiguing or distracting effects, and it should be relatively easy to incorporate into the machine system.

If these guidelines are met, the coding scheme adopted should be easy to interpret with little intercode confusion.

Coding Functions

1. Codes can aid search process

The time to search a set of candidates for a particular target increases as set size increases. (Steinberg). Therefore search tasks become more difficult (take longer and are more error prone) as the information density of a display increases. Codes can increase search speed and accuracy through a category effect.

When the target is a member of clearly defined subset of the total display, search speed and accuracy is a function only of subset size not of the total number of display elements (Egeth, Jonides, and Wall, 1872). This is true as long as the number of different subsets or categories is small (less than 4). For example, searching for a red target among a few red and many white display elements is faster and more accurate than searching for the same target when all display elements are monochromatic.

In general, items of a given category are detected faster and more accurately against a background consisting of items from a different

category as compared to a background of items from the same category (Deutsch, 1977).

2. Codes can amplify information.

Codes fulfill a highlighting function by attracting the user's attention to important information. For example, codes can be used to emphasize anomalies and abnormal states.

3. Codes can organize dispersed information.

Coding techniques are particularly valuable to integrate information that is spread across the display page as opposed to information that is already organized by rows, columns, or quadrants.

4. Codes can aid information reduction

A flexible display should facilitate several types of viewing tasks; what is relevant to one task may not be relevant to another. The user may be required to block out information that is not pertinant to the task at hand. Displays should be structured so that information reduction is a gating task rather than a condensation task. Gating requires only that the user ignore irrelevant stimulus dimensions. This activity is part of normal and often automatic perceptual mechanisms that the brain routinely uses to prevent information overload. Condensation tasks place a burden on the user's cognitive capacity since the information must be combined in complicated ways (Morse, 1979; Posner, 1964).

For example, red triangles and blue squares may have to be mentally grouped together and treated differently from a group of red squares and blue triangles.

Another way to aid information reduction is to structure displays into foreground and background. This approach takes advantage of automatic perceptual processes which differentiate figure from ground. When important and unimportant or reference information (for example, scales or grid patterns) is undistingushed, the user may suffer from information overload or he may be required to use up mental capacity in order to distinguish the priority level. Just as an information hierarchy supplies layers of information from the general to the detailed, individual displays should provide layers of information going from reference or background to important to critical information. Note that information reduction techniques are one means for keeping display density within the optimum range.

In order for the display designer to match his code selection and an overall coding scheme to the user's tasks, he must determine what information the user needs to extract from each display. This can be accomplished through a task analysis which determines the user activities each display must support.

Coding Dimensions

1. Symbology (Shape).

Graphic or pictorial symbols and shapes as data identifiers. Symbols should represent the object being portrayed. This is called iconic coding and it reduces training time as compared to arbitrary symbol codes.. Iconic coding also heightens symbol recognition and strengthens the association between the symbol and the actual object.

This effect increases the transparency of the interface.

Symbols should be simple but detailed enough to be discriminable and to prompt associations and accurate identification. The number of shapes that can be correctly identified is quite large, limited primarily by the ability of an observer to associate the symbols with the corresponding objects. This ability is dependent upon the fidelity of the symbol shape, user training, and stress (Oda, 1977). Generally a maximum of 10 to 15 different symbols are recommended for most applications.

2. Alphanumeric

Alphanumeric coding is frequently used to present quantitative information, tag numbers or similar identifiers. Any abbreviations or acronymns should be readily associated with the total word, and they should be standardized throughout the system (both on the control panel and on all CRT display pages). Alphanumerics should ideally be three characters or less because of the propensity of operators. To minimize transposition errors in identifiers such as tag numbers, alphabetic characters or other seperators should be interspersed among long runs of digits.

3. Size

The actual size of a character or symbol can be varied to convey information to the user. An operator can differentiate between approximately four or five different size variations on an absolute basis. However, for most applications, two size options are recommended, enabling a user to readily discriminate and identify the size being presented. Logarithmic (constant ratio) size variations are more accurately differentiated than linear.

Size coding is best used to differentiate between information of differing importance or symbols/components in differing states (i.e., on or off). One drawback of size coding is the larger space requirements to present the information.

4. Line Structure.

Varying line structures can be used to convey different messages to the user. Quantitative information can be communicated bv varying the length or the width of the line. Qualitative information can be conveyed by changing the texture of the line (solid vs dashed vs dotted). Line structure coding can be effectively used on graphic display presentations such as mimic displays to differentiate between flow and no flow states for the fluid or electrical current lines of the diagram.

A line structure code can be expanded into a texture code. Texture works well as a code for large fields such as areas on a graph or to indicate states on large symbols.

5. Brightness/Itensity

Many CRT systems have multiple levels of intensity which can be used in display coding. In general two levels of intensity are recommended for display coding. The effectiveness of brightness as a coding method is dependent upon the contrast of the dimmer level. If this contrast is poor, fatigue may result and information may be overlooked. If the contrast of the low-intensity option is adequate, brightness coding can be profitably used to suppress back-ground or less important information, like grid lines and labels,

which are only infrequently required by the experienced user.

6. Highlighting

Monochromatic displays provide some standard highlighting techniques which can be used to designate important information on a display or attract a user to a change of state requiring his attention. Underlining or underscoring are commonly available for highlighting information. Video reverse is an effective tool to attract an operator's attention to an important piece of information. Special symbols can be used to designate important information (i.e. arrows or bullets). Critical data values can have boxes or circles circumscribed around them to highlight them to the user. All of these methods of highlighting and attention-getting facilitate user interpretation of high density, complex display presentations.

7. Orientation

The angular orientation of a symbol or line can be varied to convey information to the user, for example clocks and dials. Orientation is a suitable coding technique as long as only relative discriminations are required. Error rates for absolute identification of angle are high for more than a few categories.

8. Flash Rate or Blink Coding

Blink coding is an effective attention getting tool. However blinking a message reduces its readability (flashing an adjacent symbol can solve this problem). Blinking also tends to be very fatiguing and annoying to users. Therefore blink coding should only be used to call the user's attention to critical events. Flash rates should be between 1 and 5 Hz (3Hz is a typical recommendation) and only one rate should be used. Because of the drawbacks to blink

coding, event acknowledge or blink suppression should be quickly available to the user.

9. Time-varying codes

Animation is a powerful way to display time-varying data. Instead of representing time with a spatial dimension on a graph, simulation time can be used to encode real time. Fast time, slow motion and freeze frame techniques can highlight information that would otherwise be difficult for the user to process. However the designer must be careful here because changes in time frame can also distort the real time information. Another example of time codes is display aiding which shows a trail of displacements that fade over time, so that a moving object or a changing data point leaves a trail of fading footprints which indicates its position or value in the recent past. Note that this example combines brightness coding with a time code to communicate trend information to the user. The critical variable for time-varying displays is the duration of the blank interval between frames. No time gap is best and if the gap exceeds 1 second, memory aiding may be necessary to provide continuity.

10. Auditory codes

The auditory modality is usually underestimated as a coding medium. However, several dimensions of sounds are available to convey information to the user in an effective way (frequency, itensity, quality, pattern, rhythm). The ear possesses tremendous powers of temperal resolution (Green, 1978). Auditory codes should take advantage of these abilities.

Because auditory codes are usually used as warning signals, a more detailed discussion of auditory coding techniques will be reserved for a separate report on Human Engineering criteria for alarm and annuciation systems.

11. Color

Color is not the ultimate answer to all coding problems. Color should not be used to the exclusion of achromatic coding methods, rather they should be used to supplement and complement one another.

Color Coding Strengths

- Color can increase detection accuracy and speed by reducing the size of the set to be searched. This is true only when less than 4 colors occur on any given display. For larger alphabet sizes, color coding can actually increase search times (Christ, 1975).
- Color is a good attention focuser when used judiciously. The utility of color coding for highlighting information is enhanced when there are only a few colors presented on the display so that a change in color from a normal condition to a highlighted condition will be readily detectable.
- Color is an effective tool for integrating physically separate pieces of data. Color coded dispersed data can easily by organized into a single perceptual unit for further analysis as a group.
- Color can be used to separate displays into figure and ground areas.

- Color is an effective means of information reduction by separating foreground and reference information. Sidorsky (1979) found that color was of value primarily for grouping data at a first level of analysis, i.e. the initial grouping of which data pieces are related to which. However Sidorsky found color was no better and perhaps worse than shape or alphanumeric coding for subsequent levels of analysis. Therefore, color coding can be effectively used to structure displayed information for subsequent analysis and interpretation.

- Color coding can be used to enhance natural representations. In some applications color is the most desirable coding modality because it most naturally represents the physical reality being encoded. For example, the red/yellow/green color assignments are most naturally associated with danger/caution/normal designations than other, achromatic coding dimensions.

- Color displays are often subjectively preferred over completely achromatic displays (Crist, 1975; Chase, 1970; Schutz, 1961).

- Color backgrounds as well as color symbols can be used to code information. For example, changing the background from black to dark blue could be used to indicate changes in plant or system mode. However, displays should be evaluated with the color background because of possible flicker effects which increase as field size increases and because of possible contrast effects on legibility.

Cautions Associated with Color Coding

- Abnormal Color Vision

It is estimated that 8% of the males and 0.4% of the female population possess some form of abnormal color vision. The most common form of color deficiency is anomalous trichromatism where a person is sensitive to three chromatic stimuli but their matches do not fall within the normal range of variation. The most common deficiency entails a weak green response (deuteranomaly) which accounts for 4.9% of the males and 0.38% of the females. A weak red response (protanomaly) accounts for another 1% of the male population. Potential solutions include screening users by color deficiencies and choosing choosing colors which are not affected by the more common forms of abnormal color vision.

- Hard Copy

In applications where hard copies of displays are required, all color coding must be used redundantly with monochromatic techniques.

- Decreased Resolution

Display resolution can be reduced on color CRTs because of the requirement to place three phosphor dots of different colors on the display face. To compensate for this, character and symbol sizes must be increased to accurately convey color information to the user.

- Misregistration

The need to align 3 beams can cause misregistration problems. Periodic adjustments will be required.

- <u>Noisey Code</u>.

The very factors which contribute to color's effectiveness as a code make it a real nuisance and hinderance to the user if not appropriately used. When not used judiciously, color coding can, in fact, degrade performance.

- <u>Spectial Sensitivity Functions</u>.

The eye is not equally sensitive to all wavelengths (see Figure 1). This means that different colors of identical physical intensities will not appear equally bright. When a variety of colours are used in the same picture, the relative intensity level of the various colours should be in accordance with the spectral sensitivity of the eye in order to avoid unintended dominance of one kind of information over another.

However, note that these brightness cues as a function of wavelength can be used by color-deficient individuals to distinguish different colors.

- Color (photopic vision) perception has a higher threshold than achromatic (scotopic vision) perception.

  Perceived colors will change and may become achromatic if the display intensity is too low. This means that higher symbol and character luminance is required for color displays than achromatic ones.

- Ambient Illumination Requirements.

  Color CRTs are generally more sensitive to ambient illumination. Contrast or luminance are usually less for color versus monochromatic CRTs and corresponding decreases in the intensity of ambient illumination may be required. The color of the ambient illumination can also dramatically effect the perceived color of a CRT. The selection of colors for information coding should be made in a situation which stimulates both the color and intensity of the anticipated ambient illumination in the operational setting.

- Color Contrast.

  When color displays are viewed for long time periods apparent hue and saturation can change due to contrast effects. The visual system processes color information in opponent pairs: red-green, blue-yellow and black-white. Prolonged viewing of one color reduces the eye's sensitivity to that color and increases the eye's sensitivity to the complementary color. Simultaneous contrast effects can also produce changes in perceived colors due to the influence of the color of surrounding areas. Contrast effects will be most pronounced when

there are large colored fields on the displays.

- Chromatic Aberration.

The lens of the eye focuses light or different wavelengths at different depths. This is called chromatic aberration. If there are many different wavelength colors on a given display, the eye cannot focus all of the colors at the same time. The accomodation (focusing) mechanisms will continually adjust in order to attempt to maintain proper focus. This effect is one major source of eye fatigue. To the extent possible, colors of very different wavelengths should be avoided in displays that will be viewed for long periods of time. This problem is the reason Human Factors guidelines often recommend minimal use of blue colors.

- Contrast Ratio

Contrast ratio is not independent of foreground and background colors. Figure/ground color relationships can increase the effective contrast ratio and thereby increase legibility. However a poor choice of colors can destroy visibility; for example, dark blue on a black ground is virtually invisible.

There may be times when less visible symbols can be useful. For example, software considerations may require that a certain symbol mark each tab point on a display. Choosing a poorly visible symbol color can effectively gate out this irrelevent information.

- Test proposed displays.

Because of illumination, luminance, contrast effects and chromatic aberration it is essential that proposed displays be tested on the actual display medium, i.e. on the CRT chosen for the application, in the appropriate environment. There is no reason that a colored drawing of proposed displays will correspond at all to the actual CRT displays. A CRT display is a light emitter and a drawing is a light reflector. the two cases do not produce perceptions that are automatically equivalent.

- Other Comments.

If single failure criteria are important, choosing colors based on 2 beams can increase redundancy. However multiple beam colors, particularly white, increase convergence problems which decrease the effective contrast of the display.

Color Code Alphabet Size.

There is a tendency for display designers to use more colors than is operationally warranted. Designers should not feel compelled to utilized all of the colors that a given CRT provides. The number of colors that can be discriminated accurately depends on wavelength, saturation, brightness, illumination, symbol size and contrast effects. While hundreds of colors can be discriminated on a relative basis, Haeusing (1976) found that only 4 colors were reliably discriminated on an absolute basis using test displays that are typical of current CRT displays.

Because of this result and because of the caution noted in the previous section, the color code alphabet should not exceed 3 or 4 hues (Wyszecki and Stiles, 1967; Burdick et al, 1965).

Recommended Approach to Color Coding

There are many coding schemes which can meet Human Factors criteria. The following is one general approach that fulfills these criteria.

Color should be used to organize displays and focus the user's attention on important information. An analogy can be made between levels of an information hierarchy and levels of a color code. An information hierarchy aids the operator to separate relevent from less relevent information by providing displays of different levels of detail. A color code should help the user separate important from unimportant information by providing different levels of organization within each display.

1. Reference or background color. This color should be clearly visible but subdued. It should not be the most salient color (i.e. not the brightest color or the one with the best contrast) available on the CRT. Static or reference material should make up this category.
2. Foreground color. This color should be the most salient (brightest, best contrast) color available. This category should include dynamic, important information, information that is necessary to fulfill the tasks the display is designed to support.

3. Highlight colors (up to 2 colors). These colors should clearly demand the user's attention for example, red for alarm information. This category should contain the least number of items, only 3 or 4 per page. If this is exceeded the color will no longer fulfill its attention getting function.

This schema organizes the information on a page into layers - almost adding a depth dimension onto the page. (Actually perceptual research shows that figures do tend to stand out on depth in front of the ground; Coren, 1976). The pyramid of layers focuses the user's attention directly onto important (foreground) and critical (highlighted) information. Within each coding level, dispersed information is organized into a single unit.

This approach can be expanded to other coding techniques as well. For example, achromatic highlighting techniques could be used and 2 levels of brightness could represent the foreground and reference information levels. However there should be a ceiling of 4 coding levels.

The coding scheme presented here fulfills each of the coding functions described earlier in a systematic way. Search performance is enhanced since information is categorized at an optimum level (3 or 4 categories). Critical information stands out through the pyramid structure and each color level pulls together dispersed but related information. The coding levels aid information reduction by organizing information according to priority levels. Finally it takes advantage of the user's perceptual and attentional mechanisms.

Human Factors recommendations on coding usually provide an annotated list of eight colors (the eight colors usually available on CRT systems). Each color is matched as best suited for different types of information. No such list is provided here because it encourages the overuse of color coding and because the appropriate colors for each application should be determined by test trials with the actual CRT, displays and visual environment.

Interactive Techniques.

Coding techniques are not the only means available to facilitate operator processing and interpretation of complex displays. Interactive capabilities can be incorporated into the system to enable users to separate relevent from irrelevent information. On some CRT systems, multiple graphic planes can be utilized for different groups of information so that an operator can suppress or request information as required. Gridlines, labels, units, scales, and limits are all candidates for suppression by an experienced operator. An operator should also be able to interactively request supplemental information that does not warrant continuous display. For example, on a graphical display, an operator could request a digital display of actual or historical parameter values. Interactive techniques can be effectively used in addition to coding methods to reduce the density of complex displays.

Table 1 - Alternative Coding Dimensions for CRT Applications

Dimension	Recommended Number of Levels	Alternative Applications
Symbology	10 - 15 max	Identify different components and their operational status
Size	2	Highlight dynamic vs. static data
		Highlight operational vs. non-operational components
		Differentiate piping with flow vs. no flow
		Highlight more important data, symbols, or lines
		Differentiate monitored vs. non-monitored data
Line Structure	3 - 4	Differentiate flow vs. no flow
Brightness/ Intensity	2	Suppress background info
		Highlight caution and warning information
		Differentiate operatational vs. non-operational components
		Differentiate piping with flow vs. no flow
Color	3 - 4 recom.	Differentiate dynamic vs. static data
		Highlight caution and warning information
Achromatic Highlighting	on/off	Highlight caution and warning information
		Differentiate operational vs. non-operational components

Candidates for Coding in Process Control

- Various media (steam, water...)
- Conditions or states (on/off, running/stopped, open/closed, flow/no flow. available/unavailable)
- Control modes (manual/automatic, remote/local)
- Plant status (pre-trip/post-trip, terminate/mitigate)
- Information priority (alarms)
- Background or reference information versus foreground information
- Data quality (good/inconsistent/bad/manually entered)
- Information state (normal/cautioning/abnormal)

There are many useful ideas on how to apply coding techniques to different applications. It is not sufficient to match one coding candidate to one coding dimension until the set of candidates is exhausted. This approach will guarentee an unsatisfactory coding scheme. Coding questions must be examined as an integrated set together with information transfer requirements generated via task analysis. This approach will prevent conflicts between individual codes and it will prevent coding schemes which increase, not reduce, display complexibility.