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Technical Report

**A Guide to Using Color
on Alphanumeric Displays**

**P.J. Robertson
IBM U.K. Laboratories Limited**

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Preface

This document is intended for use by programmers, systems engineers, and others involved in the design of multicolor alphanumeric display applications. It assumes an elementary understanding of VDU applications, color terminology, and color vision. Publications providing introductions to these topics are included in the reference list at the end of the report.

The purpose of the report is to provide guidance on the best approach to implementing color display applications so that some common mistakes can be avoided, and to explain the human factors reasons behind the recommendations made to application designers, so that design decisions can be based on a better understanding of the issues involved.

The report supercedes Hursley Human Factors Laboratory Report number HF012.

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Introduction

This report summarizes the ideas and recommendations on the use of color on computer VDUs (visual display units) arising from three year's experience of working on color displays in the IBM Hursley Human Factors Laboratory. As well as examples of the ways that color might be used in a variety of applications, the theoretical and practical considerations leading to the choice of particular methods of employing color are described. Those technology characteristics of color CRTs (cathode ray tubes) that affect color choices are included, although most of the factors discussed apply to multicolor devices in general.

It is emphasized that the majority of our work has *not* been concerned with application trials or the testing of various methods of employing colors in running applications. Very little experience has been gained in the field. It is therefore likely that many new ways of applying color have yet to be invented, and that some of those suggested here will be modified in the light of experience.

The reader is assumed to be familiar with VDUs, with the basic concepts of color and color vision, and with common alphanumeric applications. The reference list at the end of the report includes publications that describe these topics, for the reader who needs further explanation.

One simple way of using color is to augment the way that conventional formats aid the operator in understanding the logical structure of the data on the screen. For instance, it is common to show the structure of the data by separating headings spatially, by using upper- and lowercase, and by grouping similar or related items. Color can be added directly to strengthen these formatting techniques: headings in a different color; logically related data in one color and logically unrelated data in different colors. Where the color merely reinforces existing formatting techniques, it is in effect redundant, and the same formats can obviously be used on monochrome displays and by the color-blind. However, the color will also be able to show relationships and differences independently of other formatting techniques: for example, using the same color for fields that are related but spatially separated. This use of color is described more fully in the section "Color as a Formatting Aid".

The other major use of color is as a code, showing the operator which categories the data being displayed falls into. If the categories are chosen carefully to be relevant to the operator's task and the color codes are clear, then the operator should be able to do the task more quickly or more easily. This is because at a given step in the task the operator can identify the relevant category on the screen quickly and can then concentrate on that category, excluding the data in other colors from his attention. In other words, the operator can select the relevant fields from the others without first having to read the contents of the field. More details of this use of color are described under the heading "Color as a Visual Code".

The application designer therefore has two types of decision to make: what categories the data should be divided into, and which color to use for which category. The first clearly depends wholly on the application and will vary markedly, particularly between applications designed from scratch with color coding and those where color is added later. The section "Choosing the Categories to Be Colored" discusses some of the general considerations affecting these decisions and gives more specific examples.

The section "Choosing the Colors to Be Colored" describes the areas to consider when assigning colors to categories of data, including the expectancies of the operator, the number of colors to be used, and the characteristics of the display device that affect this choice. Appendix 1 outlines some of these characteristics for the IBM 3279 Color Display Station.

Color blindness, its effect on users of multicolor displays, and some suggestions on improving color discrimination by the color-blind operator are given in Appendix 2.

Appendix 3 gives examples of some of the points raised in the text: both good and bad use of color.

The summary includes a list of the more general recommendations given throughout.

Color as a Formatting Aid

Using color for emphasis and to show relationships as described below is in effect using it as a formatting aid. It can also be used very simply to enhance achromatic formatting without changing any other aspect of the picture. Though limited, this use of color will appeal to those running existing monochrome programs on VDUs who want to make as few program changes as possible. Using the 3279 base color approach, some applications will achieve a sensible color scheme with no program changes at all, but many will need some alterations to the attribute bits which determine color.

A common division will be between headings (or field names) and the data under them. This simple use of color can help the operator on screens where the formatting is poor or confusing, but is unlikely to produce significant performance improvements. Wide blocks of data can be broken up into groups three rows deep with alternate colors in the same way that printed paper has green and white stripes. This helps when following long horizontal lines of data and guides the eye when jumping from the end of one line to the start of the next. Finally, if the formatting breaks up the data into columns, blocks, or other groupings it can be enhanced by coloring the groups differently.

Emphasis or Attention-Getting

In its simplest form, this use of color replaces "bright-up" as a means of emphasizing fields or characters on the screen. It is, however, much more flexible because of the number of colors available and their ability to combine with achromatic highlighting. Any field can be emphasized simply by making it a different color from the fields around it. This will obviously be most effective when the screen is relatively uniform in color - one red field in a screen full of green will stand out more than a red field in a screen of other red fields and several other colors. Thus emphasis of one field is increased by de-emphasis of the others.

Some colors will draw attention more readily than others, for psychological and physical reasons. The psychological reasons include the subjective associations of the color (for example, red for danger) and the operator's set (that is, whether the operator is looking, or disposed to look, for that particular color). The main physical (or physiological) reason is contrast. The brightnesses of 3279 colors increase in the following order: red, blue, green, pink, yellow, turquoise, and white, and most color CRTs would be similar. Blue is generally felt not to stand out strongly against the dark background of the screen. Therefore blue may be used to de-emphasize fields, and bright colors such as white to emphasize fields against duller colors.

Relating Fields

Where two or more spatially separated fields are logically related, this can easily be communicated to the operator by displaying them in the same color. This is particularly useful where a change in one field during the task has an effect on another field that would not have been obvious to the operator.

Where the similarly colored related fields are not spatially separated, the effect is to form a block of fields that are clearly related to each other and separated from the rest of the data on the screen. For example, a motor insurance inquiry application displays a summary of a customer's policy conditions. This includes drivers covered, details of the vehicles insured, restrictions and conditions, premium

calculation, and administrative details. Each of these groups of data could be in a given color, enhancing the identity of the group. If the operator were to make a change to the drivers covered, the changed field could be emphasized in another color, and fields in other groups would also be emphasized in that color to show that they had been affected by the change (for example, the premium and restrictions might change). Thus all the fields undergoing change would be related by color and drawn to the operator's attention.

Similarities can be communicated by using similar colors. For example, if red is used for severe problems pink could be used for less severe or secondary problems. With a restricted set of seven colors, it may be necessary to point out the similarity of the colors used, at the same time as the similar status is being explained to the operator in training. However, with a greater variability of color available (through graphic toning techniques, for example) the similarities will be obvious and will even allow continuous scales to be represented by fine gradations of color.

Clarity of Graphics

Graphic uses of color are briefly described in a later section, but color can add clarity to even the simple graphics available on alphanumeric machines. For example, color can be used to differentiate two closely plotted lines. Thus curves on a graph can be followed more easily, and lines can be superimposed in simple illustrations without confusion.

Achromatic Highlighting and Formatting

A number of achromatic techniques can be used for emphasis, alone, or in combination with color. They will be particularly useful where emphasis is to be imposed on a color-coded application where the use of color is restricted to specific meanings. Blinking, reverse video, and underscore can be very effective as attention-getters if used in moderation. Like colors, if they are overused they are not effective because they become distracting.

Blinking is so effective that its use should be strictly limited to occasions when the operator must respond quickly or be able to detect the signal when some distance from the screen. It is also advisable to stop the blinking once the operator has responded, so that his attention is not distracted from the information being displayed. Note that these techniques reduce legibility and increase susceptibility to flicker. Underscore, for example, masks the lower profile of words and a single horizontal line is prone to flicker on interlaced displays.

Using space and position on the screen, special characters, and simple graphics can also be used for emphasis and attention-getting, and can be effectively combined with color. These techniques transfer successfully to printing but should be used conservatively: a page scattered with blocks of asterisks can be just as annoying to read as one full of blinking reverse video blobs.

Color as a Visual Code

In this document, the term "color coding" implies that the color of a field conveys information about the field to the operator: that is, the color has a definite meaning. The approach described in the previous section uses noncoding color to improve the clarity or format of a picture without regard to the data's meaning; this section discusses the use of color as a code that has meaning to the operator.

Performance Studies

Many studies on the effect of color coding on subjects' performance have been carried out, and are comprehensively reviewed in Christ (1975). The majority of the studies used very simple tasks (search and identification tasks in particular) that were designed to provide sensitive measures of the effect of color coding and that are not intended to be representative of VDU operators' jobs. Also, the display medium used was rarely the CRT. Therefore the findings of these experiments are not suitable for estimating of "productivity gains" due to color. They do however provide some guidance to ways of employing color in displays and form the basis for many of the recommendations here.

Relevance

Probably the most crucial aspect of the way color is used is its relevance to the application. This may seem an obvious point, but there are many examples of use of irrelevant color. The effectiveness of visual coding is due to its ability to attract the operator's attention to a particular class of data on the screen, and to enable the operator to attend selectively to that data. This means that the operator does not have to scan the contents of the other fields first in order to find the right one. Color is particularly good for this purpose because it is quickly and reliably recognizable: other codes (for example, shapes) may require more mental processing and therefore be slower.

Relevance is achieved when the color code enables the operator to attend selectively to the field containing the data that the operator needs. For example, in a scheduling application the urgent jobs could be shown in pink, allowing them to be easily found among the other items in green. This would allow all the items to be arranged in numerical order so that specific references can be traced, and color codes useful to other users could be included (see Figure 1). If this picture were to be used in the accounts department, however, the coding would be irrelevant. The user would be more interested in the cost mismatches than the due dates and emphasis of the "urgent" rows would be irrelevant. This irrelevant color coding might well distract attention from the items of interest and thereby make the task less efficient.

As well as the code being relevant to the operator's task, it is important that the operator knows what the code is, otherwise it is not only useless but can distract the operator and degrade performance.

The tendency to use color to make "pretty" pictures or to construct pictures that show off all the capabilities of the display at once should be avoided when constructing applications, because the color in these pictures will be irrelevant to the operator's task and extremely distracting. This will reduce the operators' productivity and in extreme cases can quickly become objectionable to use.

The best approach is to analyze the operator's task and note the ways in which data is selected from the screen. If the operator uses one type of data in one part of the task and then another type in a later part or under different circumstances, code the different classes of data accordingly, to help the operator make these selections. When considering the examples of color-use suggested later in this report, bear in mind that what may be useful in one context may well be an interference in another.

Achromatic Codes and Multidimensional Coding

Color can be used as the sole code on a given screen, or in combination with other codes. The application designer should plan the use of the achromatic codes in conjunction with the color codes. (A hidden advantage of color is that it encourages the programmer to think about the way he presents information to the operator in general, not just the colors.) It has been shown that color can be very effective in combination with other codes, whether it is used to provide different information from the achromatic code (nonredundant coding) or to code the same information simultaneously with the other code (redundant coding). Both types of coding will not be used on multicolor VDUs, but because most of the simpler applications will be monochrome-compatible they will use redundant coding automatically.

In this context the achromatic codes referred to include not only the highlighting techniques of blinking, reverse video, and underscore but also coding using characters, position on the screen, and shapes, sizes, and toning of symbols.

In experiments where visual codes have been used to identify data categories whose identification is an essential part of the task, using more than one coding variable has been shown to improve human performance. A classic study by Erikson and Hake (1955), for example, showed that three variables (brightness, hue, and size) could be used to code far more categories than could be successfully comprehended by the subject if only a single coding variable was employed. In the same way, color coding can be used in conjunction with existing achromatic codes to much better effect than if they were used alone. For example, a personnel manager might want a display showing the usage of some employee benefit at his company's major European locations. Each location could be coded on the chart by a combination of color for country and shape for type of activity. (Blue for the UK, green for France, white for Scandinavia, etc. and square for manufacturing, triangle for development, circle for marketing, cross for administration, etc.) In this way he could deal with say seven colors for major European areas and six shapes for functional divisions and hence could easily classify the items on his chart into 42 categories. As well as being able to spot differences between the UK and Germany or manufacturing and development, he could note that marketing in Italy, say, was different from other marketing and other Italian locations in general. To code 42 categories by color or shape alone would clearly be unmanageable. If required, the size of symbol could be used to indicate the number of employees at a location, and so on.

In practice, one of the codes will frequently be alphanumeric. Because we are so practiced with this type of symbol we can use it to define an almost infinite range of meanings without difficulty and do not usually regard it as a visual coding technique.

If a complex color code is being used it may be worthwhile to reserve the highlighting techniques for noncoding formatting and emphasis independent of the use of the color. This would allow flexibility for the programmer to draw attention to

particularly important or unusual fields without the restrictions that might be brought about by a too rigid and specific standard. Thus an application or installation could employ a standard color code that implied fixed specific meanings for the colors and a much looser use of achromatic highlighting for nonspecific emphasis.

Finally, migration and compatibility between devices must be considered for achromatic codes as well as for color. The possibility of interdimensional translations of codes does arise (for example, print italics for turquoise fields or use a particular pattern on a monochrome display to represent a particular color on a multicolor one) but it is very complex and has not really been studied. All this report can recommend, therefore, is caution.

Choosing the Categories to Be Colored

The simplest way of categorizing the fields on the display is on the basis of their screen format types, independently of the data values contained in the fields. The separation by color of headings and "data" is an example of this that has already been described.

Other color codes that are independent of the content of the fields include indicating the source of the data in a field by its color, and some types of status coding. In a document preparation system, for example, the sources of various paragraphs or items could be shown by colors. Alternatively, the status of these paragraphs could be color-coded into categories such as original version, edited version, approved technically, approved legally, reviewed by various departments, final version, etc. In a document that is continually being changed as comments and reviews are received, this could help the author to keep track of who has approved which sections of his document. Another type of source coding could show the operator which parts of the computer system generated the fields on the display. This might involve one color for operator-entered data, one for program-generated data (such as headers, results of calculations) one for data from a data base, one for system messages, and so on. In development of complex programs, this could help the programmer keep track of which part of the program produced a given output.

Many of the status-monitoring applications that employ colored charts or graphics use nonredundant color coding. Power network monitoring, for instance, typically uses shapes to identify components of the system and color to code their status (on/off, working/failed, degree of loading, etc.). This use of color avoids having to add more symbols or characters to complex displays.

Color can be used to code physical variables, such as temperature in an application involving furnaces or altitude in air traffic control. In these cases the choice of categories must take into account whether the variable being coded is continuous or has discrete steps, and how many categories the display and operator can deal with adequately. This type of coding also implies an order for the categories (say from low to high temperature) and therefore requires a recognizable sequence of colors. This is discussed further below. Very often a key or legend will help the operator discriminate the colors in this type of application.

The applications discussed up to this point have used color to provide information that is not otherwise contained in the fields being color-coded. (Although it may have been implied by their position on the screen or other achromatic codes.) In many cases, however, the color code will be redundant. That is, it will be providing information that is already being displayed in another form.

The most common case will be where the color of a field is dependent on its content, the color simply reinforcing the alphanumeric data. This use of color is particularly useful where the application has to be monochrome-compatible and is likely to be the way that color is introduced to existing monochrome applications. It also ensures that the color blind and those who have not yet been trained to use the color can still operate the terminal satisfactorily.

In some applications, a group of fields will be colored according to the value in one of them. Examples of this include the colors of rows in tables being determined by the value in a significant field (see the machine shop example display) and cases where a change in one field affects the values in other fields, which are color-coded accordingly as in the motor insurance example.

The color-coding may also be dependent on the status of the operator/display transaction, where color is used to indicate the impact on various fields caused by a change entered by the operator. Color can also be used as a prompt, guiding the operator through a transaction with a complex picture. This can be done by highlighting the next field to be entered, or by selectively coloring those fields that are still eligible for operator action following previous actions.

Finally, it is stressed that the categories into which the color code classifies the display fields must be chosen so as to aid the transfer of information from the display to the operator. This requires a clear understanding of the way the operator uses the information. If the operator deals with different sets of fields separately, then color-code the sets to help the operator attend selectively to each in turn. If the operator makes decisions based on the status of a field, then color-code the various types of status the field can have. If the operator searches the display for fields of a particular status, then make the color of such fields contrast with the rest. If certain fields are hardly ever used by the operator, display them in an unobtrusive color (if they cannot be removed completely). If the sequence in which the operator changes fields is constrained, use color to guide the trainee or casual user through the sequence. When considering the color-coding strategy, also consider the spatial formatting, highlighting, and messages that can aid the operator.

Choosing Colors for Categories

Having chosen the categories into which the color code will break the display fields, the application designer must then assign a particular color to each category. Some considerations affecting this decision are discussed in this section. In short, they are as follows.

Consistency is important if the operator is to use the color codes efficiently, and it is likely that installations will have standard uses of colors. It is also important to match other color codes in the operator's job as closely as possible. Color associations and expectancies from everyday life must also be considered.

Consider the physical characteristics of the colors available: for important fields and emphasis use bright colors, for background information use low-contrast colors. Display characteristics to look for are described further on in this section, and the relevant aspects of the IBM 3279 are described in Appendix I.

Choose sets of colors that are easily discriminated if they are used to identify different categories, and use contrasting colors for emphasis and separation. To show similarity, use similar colors. The following list gives contrasting, easily discriminable sets from the seven colors available on an alphanumeric 3279: red/turquoise, blue/yellow, green/pink; red/blue/green; red/blue/green/white. Pairs of similar colors include red/pink and blue/turquoise. In applications where larger sets of colors are available through graphics toning, use the paleness of some tones to contrast with the more saturated colors, but make full use of the different hues available in the saturated colors before using very many pale ones.

Another factor to consider is the frequency of use of different categories, and the relative importance of correct identification. If the bulk of the data falls into one category (often called "normal") then a clear color without strong associations should be used for that category (usually green). The colors of other categories may then be chosen to contrast with the "normal" one. If accurate discrimination between two categories is particularly important, then two clearly different colors should be chosen for these categories first (such as blue and yellow) and colors assigned to the less critical categories afterwards.

The question of the order of colors used to represent categories with an inherent sequence was briefly mentioned above. If the color is used to code values of a more or less continuous variable, then it helps the operator if there is an apparent sequence in the color code. Some variables may have color associations that can help, such as the resistor value color code or coding temperature from black through red and yellow to white. If no special order is apparent then an approximation to rainbow order can be used, or if the operator understands the way that the various colors are produced the order of colors in a color triangle can be used. For these latter cases, Poulton (1976) recommends red for the high-value and white for the low-value end of the sequence. With the graphic toning techniques it may be possible to simulate a continuous spectrum (from red through orange, yellow, lime, green, etc.) rather than explicitly breaking the sequence into discrete steps. In this case, or where a large number of steps is used, a key at the side of the display will help the operator to judge a color's position in the scale.

Finally, compatibility between display and printer and between color and monochrome displays must be considered. If the same code is to be used on more than one device type, the device with fewest colors may determine the choice for the other device. Color "translations" must be made carefully and explained to the

operator if they cannot be avoided. One "standard" translation is white on the display to black on the printer, and white on 3279 in "monochrome" mode for high brightness on monochrome displays. (Hence the suggested use of neutral for nonspecific emphasis.)

Subjective Reactions to the Colors

Color ought to be employed in an objective, rational manner that will enhance information transfer between the display and the operator. Therefore the subjective preferences of the application designer ought not to be allowed to impact his use of color on the screen. (For example, the fact that a given programmer likes red is not sufficient reason for his applications to use predominantly red pictures.)

This is not to say that subjective views on color are to be completely ignored - on the contrary, the designer should consider the operators' reactions carefully when choosing how to employ color in his application.

It has generally been found that operators or experimental subjects prefer multi-color displays to monochrome ones (Christ, 1975; Robertson, 1976). This is important in that it provides a potential to increase operator satisfaction. It should be noted, however, that this subjective preference is linked to observers' judgment of display effectiveness; color may be judged to be more productive or more suitable than monochrome even in situations where this is not the case. Care must be exercised when evaluating applications in color for this reason.

Occasionally it may be reasonable to take account of operators' preferences for particular colors. If all the users of a given application or system dislike pink, then by all means avoid it. In practice, however, these preferences vary considerably from one individual to another and therefore cannot be consistently useful.

One example of the difficulty of relying on subjective judgment is an occasional reaction that the blue on 3279 is "not blue enough." It appears that the 3279 blue is too pale to fit some people's predetermined concept of blue. In a naming experiment, however, when subjects were asked to give a name to a similar color, over half called it "blue" and 27% gave it the name blue plus a qualifier (for instance, "pale blue"). Other observers have expressed a desire to have a blue paler in order to make it more suitable for reading in large text fields. (A deep, or "saturated", blue is more difficult to read than a pale blue because the high-resolution part of the retina has low sensitivity to this color.) Therefore there are objective reasons for the choice of the color, which must take precedence over subjective reaction. The reactions to red are also contradictory: comments include "I like that orangey red." "Your red has too much orange in it." "I find the red very dull and hard to read." "That glaring red makes my eyes smart." "The bright red really makes errors stand out." It is clearly necessary to make the design decisions on other grounds.

If it is intended that an occasional application be decorative rather than designed to transfer technical information, in this case subjective preference can be allowed full rein.

User Expectancies

While the user's likes and dislikes are difficult to employ when designing applications, some operator reactions to colors have a more practical basis. If the application uses a given color consistently in a logical manner, then the operator can infer meaning from the use of that color and information is therefore transferred from the machine to the operator by means of the color. The operator will find this

much more difficult if he is used to that color having a meaning different from the meaning employed in the application.

To take an extreme example first: the electronics industry uses a well-known color code to indicate the values of resistors. In this code, colors represent numerals and thus have an ascending sequence: black = 0, brown = 1, red = 2, orange = 3, yellow = 4, green = 5, blue = 6, violet = 7, grey = 8, white = 9. Supposing a worker in this industry had to use a display where daily production figures were color-coded. It is obvious that the user would have great difficulty in interpreting the displayed information if the color code chosen by the programmer was red = 0 units, blue = 1000 units, green = 2000 units, white = 3000 units, etc.

It is therefore important that existing color codes be taken into account when choosing codes to be used on multicolor VDUs. Many of these codes are much simpler than the one described above, for instance the use of red ink in financial statements, red for stop and green for start on machine tool controls, traffic lights, fire extinguishers, electrical wiring, colored symbols on year planners or timetables, and colored status lights on DP equipment. Other uses of color may not be normally thought of as "coding" but could affect an operator's expectancy: keyboards with different types of keys in different colors or tones, warning lights on car instrument panels, editors' blue pencil, soccer referees' yellow and red cards, and so on.

Clearly, the closer the use of color is to the application being designed, the greater will be its effect on the operator's expectancies. The programmer should therefore look for color uses that already exist in the operator's job, and try not to conflict with them. The more "remote" uses of color do help in choosing colors within an application, however, because they not only form an operator's expectancies but also act as indicators to some general way in which color is commonly applied. The most obvious example is red, with its associations of "stop", danger, and so on. For this reason, the use of red for error messages, problem identification, and highlighting specially significant fields is generally accepted.

If two levels of severity need to be signalled, yellow and to a lesser extent pink associate well with red.

It is necessary to employ a color ordering scheme that is well known: red, orange, yellow, green, blue, indigo, and violet. If no other sequence presents itself, rainbow order is quite suitable for coding continuous variables, as described earlier. This would produce the following order of 3279 colors: red, yellow, green, turquoise, blue, pink, and white.

The Number of Colors to Be Used

Studies of alphanumeric applications have shown that they rarely need more than seven and often only four colors. Apart from the coding demands of the application, the capability of the operators to deal with many colors must be considered. This is described in "Discrimination and Identification" below.

Graphics users often require a larger number of colors in order to construct complex pictures or to allow the choice of finer graduations of color. These needs can be often satisfied by color toning techniques (see "Graphics" below).

Discrimination and Identification

Whatever the total number of colors employed in an application, it is clear that for

them to be of any use to the operator he has to be able to tell one from another. If this discrimination is not possible, then fewer colors can be used to the same effect, and human factors workers have therefore studied this area with the objective of setting an upper limit of usefulness on development. The results vary from "about seven" to "7,495,000" (Chapanis, 1965) depending on the type of discrimination required by the application. The higher figure is an estimate of the number of colors that are detectably different when viewed side by side, but clearly has little practical value to data display. The lower number, seven, is an estimate of the number of CRT colors that can be reliably identified when viewed singly, at typical brightness and symbol size, by an unpracticed observer with normal color vision. The latter estimate has been tested experimentally with 3279 phosphors in the IBM Hursley Human Factors Laboratory.

If a given application requires that more than seven colors be identified without error, the following techniques will improve identification accuracy:

- Use large colored symbols (greater than 1 character block)
- Train and practice
- Keep the display bright
- Choose the colors carefully to be as well spread throughout the spectrum as possible
- Fuse a legend or key so that comparisons can be made
- Fuse simple descriptive names for the colors ("turquoise, pale blue, deep blue, violet" rather than "blue 1, blue 2, blue 3, blue 4")

These techniques will also help the color blind, and others using the display in difficult circumstances.

Relevance and Confusion

The previous subsection explained that the seven colors are reliably identifiable and can therefore be used with few errors. This does not mean that all seven should necessarily be used. First, the total number of colors in an application must be chosen with regard to the needs of the application: if seven colors are *useful* to the operator, then use them; if only three types of data exist, then use only three colors. This is essentially the issue of relevance discussed earlier.

Second, it is a unanimous subjective finding that too many colors on the screen can make it confusing or even unpleasant to look at. What constitutes "too many" varies from picture to picture, but using more than four colors often produces this comment on typical alphanumeric pictures. Graphics pictures can generally employ more colors if they are used with care. (This may require the advice of a graphic designer.)

This does not mean that alphanumeric applications should be restricted to four colors: an application can use seven colors but display only a few of them simultaneously.

Consistency and Standards

If the color of a field is expected to convey information to the operator, it is obvious that the operator needs to know the meaning of each color being used. The operator has a much better chance of interpreting the color if it is used in a consistent manner. This applies at the level of the picture, the application, and the set of applications used by the operator. The value of consistency with color meanings encountered away from the terminal has already been discussed under "User Expectancies".

The degree of consistency required at a detail level depends on the nature of the application: if the colors code very specific values (for example, turquoise could mean that an aircraft is at 10,000 ft in an air traffic control application) then even a slight variation in implied meaning will cause confusion or errors. If the meaning is defined more broadly (for instance, red means there is a problem) then there is much more scope for variation without inconsistency. The application designer therefore needs to consider the present and future applications to be used by the operator before deciding how specific the information implied in the color should be.

Migration and Compatibility

The problem of achieving consistency between applications is further complicated by the need to achieve consistency between devices. This arises when more than one type of terminal can be used for an application and when existing machines are replaced. A discussion of the current IBM 3270 display family can illustrate this. It is possible at present, for example, that an installation will require consistency between several or all of the following: 3278 and 3277 monochrome devices, 4-color 3279, 7-color 3279, 7-color 3279 with Programmed Symbols (PS), and the 4-color 3287. (Refer to the glossary for brief descriptions of the IBM 3270 series.) The 3279 has not been designed to be completely consistent with monochrome displays - it is compatible to the extent that monochrome programs will run on any model of 3279, but even in "monochrome mode" two colors are displayed, white replacing the high-brightness available on the monochrome machines. The example installation, therefore, may reserve the colors green and white for "normal data" and "nonspecific emphasis" in order to be consistent with existing applications being run on 3279.

It seems likely that the majority of 3279 users will fall into one of two categories of color-use because of these factors. The first will use the four base colors for very broadly defined data categories (such as "normal data", "general emphasis", "problem message", "background information") in order to overcome the restrictions of base-color mode and to achieve consistency between the variety of terminals mentioned above. The applications are likely to be almost entirely alphanumeric, and at first they will be mostly monochrome programs with minor modifications, if any. The developers of future 7-color applications for these users will therefore face the choice of being restricted to three colors for new or specific data categories, or of using colors inconsistently, or of changing their use of color to meet new application requirements.

The second group will require more specific color codes and will therefore be constructing new application programs, presumably on 7-color 3279s. Graphics will be much more widely used in this group. Some problems may arise if operators frequently use more than one application: the designers may have to compromise either color consistency or specificity of meaning associated with color codes. A combination of common broad categories and narrow categories specific to

different applications may also be successful in this case, particularly where graphics techniques can produce a large number of available colors.

There is a danger, then, that using a variety of terminals or migrating from one type to another will result in a plurality of color-coding schemes, to the confusion of the operator. The solutions appear to be either to employ a standardized, detailed color-coding scheme, which can be adhered to consistently throughout an operator's applications and devices (at the cost of an initial planning and programming effort and perhaps fully featured devices) or to keep the initial uses of color simple and broadly defined, allowing flexibility without incompatibility. Users should be encouraged to adopt one of these strategies, rather than risk uncontrolled development of inconsistent codes in different applications and incompatibilities within applications using more than one device type.

Characteristics of the Display Device

The application designer should consider a number of characteristics of the display device to be used when assigning colors to the data categories chosen for the application. The chromaticities (exact colors) of the available colors are obviously important, both in terms of their identifiability with the colors that the operators expect and in the ease with which the different colors can be distinguished from each other. The chromaticity may also have implications for legibility, as in the case of deep blues discussed above or for color-blind operators if the red, for example, has not been chosen by the designers of the device with protanopes in mind.

On CRT displays at least, the colors also vary in a number of other ways due to the differences in the phosphors used to obtain different colors. Brightness and sharpness both vary and could affect legibility. Brightness also affects a color's suitability for emphasis. Secondary colors are almost always brighter than the primary colors that make them up, but the quality of the convergence and its degradation of legibility if poor must also be taken into account when secondary colors are to be used. Obviously, if a high proportion of the data is to be displayed in one color then a clear one should be chosen.

If another device, such as a printer, is to be used in conjunction with the display then the characteristics of its colors should also be borne in mind while the choice from the display's set is being made: the impact of the printer's characteristics on the choice depends on the relationship between the devices within the application being considered. Appendix 1 describes some of the colors available on the IBM 3279 from this point of view.

Graphics

A comprehensive discussion of graphic techniques is beyond the scope of this report. A graphic guidelines document with human factors contributions is planned in support of the IBM Graphical Data Display Manager (GDDM) program product (Murphy, 1979). This section will therefore be confined to a few pointers on the use of color in graphics, on the IBM 3279 in particular.

The 3279 with PS (Programmed Symbols) allows a large number of apparently different colors to be displayed by means of toning patterns composed of different numbers of pels (picture elements) in the primary colors. For example, a 9x12 character cell with 50 green pels and 50 red pels appears yellow; with 30 green pels and 70 red pels it appears orange. The number of variations is clearly very large, and as an aid to the programmer, 64 standard fill colors have been provided in GDDM. The user should select from this set the number of colors he needs, picking ones that are as different from each other as possible (if the application requires good discrimination). (In practice this involves using more of the stronger colors and fewer of the pale ones, which are less discriminable.)

The availability of more than the seven basic colors can cause difficulty for the operator if he is expected to be able to identify each of the colors reliably. Therefore do not use more than are necessary for the application. In some cases the colors will be used simply to differentiate areas of the picture visually and no specific meanings will be associated with the colors, but where this is not the case, the operator should be given as much aid as possible to identify the colors:

- Provide a key or legend
- Be as consistent as possible between pictures, applications, and other color codes in the operator's job
- Choose discriminable sets of colors, tones, and patterns. For example, aid the discrimination between three shades of pink by using a pattern with the basic pink, and choose the other two tones to be as different as possible.
- Use large areas if possible. The operator is less likely to make color identification errors with areas of several character blocks in size than with single characters.

The toning and fill patterns provided as standard have been carefully chosen to minimize flicker, which is more likely to occur with graphic pictures. The picture designer is advised to avoid flicker-sensitive patterns as much as possible, by taking account of the following points:

- Patterns that have equal numbers of on-pels in the two interlace fields will flicker far less than those that have an imbalance between the fields.
- Single horizontal lines fall into the above imbalanced category: use two-pel-wide horizontal lines where possible.
- Large, very bright areas will tend to increase perceived flicker more than less bright toned areas.
- The color most prone to flicker is white, followed by pink and yellow, turquoise and red, blue, and green in that order.

Murphy (1979) has also pointed out that "staircasing" is more apparent in some colors than in others, green being most prone with red, blue, and pink less prone to the effect (which is presumed to be due to the sharpness of the green spot).

The graphics features and software also give the programmer more flexibility with the alphanumerics on the picture. Where the application requires special fonts and so on, this is very useful. Annotations on graphs, however, are best left simple for optimum legibility: color-on-color, toned characters, and highlighting should be used conservatively. Legibility can be improved by the use of larger characters, both because of the character size itself and because more pels allow more freedom in character design, and this might be very useful in presentation applications where the screen is viewed from a greater-than-normal distance. For the best results make the whole character larger, not just double height and "normal" width.

Summary

This report discusses the human factors issues involved in using multicolor computer VDUs. Ways of using color ergonomically and the relevant psychological, physiological, and technological considerations are described. The guide covers using color as a formatting aid, using color as a visual code, how to choose the categories of data fields to be colored, and how to choose which colors to display those categories in. The incidence, nature, and implications of color blindness are briefly reviewed. Although the report is intended to be general, particular reference is made to the IBM 3279 Color Display Station, including a review of the 3279 characteristics affecting the choice of colors for data categories.

Both general and detail recommendations are given throughout the report. A summary of the general recommendations follows.

Recommendations

Relevance. Ensure that the way that the color is used on the screen is relevant to the operator's task. Analyze the way that the operator uses the information, and use the color to help. (See pages 4, 8, and 12.)

Consistency. If the operator understands the way that color is being used, and it is being used consistently, then it can transfer information to the operator quickly and effectively. Consider whether color-use standards will help to achieve this. (See page 12.)

Match the operator's expectancies as much as possible. As well as maintaining consistency within and between applications, try to achieve consistency with other uses of color in the operator's job and with color associations from everyday life. (See page 11.)

Use color rationally. Do not use colors just because you like them, but for objective reasons. Take account of operators' reactions but do not be ruled by their subjective preferences, which will differ from person to person. Quick subjective judgments of the value of color are often unreliable. (See pages 8 and 10.)

Use color conservatively. Avoid the temptation to show off the colors and highlighting. Use the number of colors that will help the operator, and no more. Overused or irrelevant color is confusing and distracting. (See page 12.)

Appendix 1: Characteristics of IBM 3279 Colors

As well as more general questions concerning the use of color, in practice one must take account of the characteristics of color actually available on the display. The relevant aspects of the IBM 3279 and the color 3287 are therefore described here so that their implications for the application of color may be considered.

The A models of 3279 have four colors with restricted program control over their arrangement on the screen and are intended to add color to existing monochrome applications. The four colors are red, green, blue, and white.

Green is the primary color with best brightness/sharpness characteristics and is also the "standard" monochrome color. Its use for the bulk of standard data is therefore recommended. It is also recommended as the appropriate color for monochrome and default applications.

Blue on the 3279 is a fairly desaturated color, arrived at as a compromise between reading ease (which requires a pale blue) and discriminability (which requires a deeper or "bluer" blue). It is generally felt subjectively to have low contrast with the screen background, and its use as the color for "background" information such as the operator information area, fixed headings ("boilerplate") and nonsignificant data is therefore recommended.

The red on 3279 has a slightly greater spot size than the other two primaries at a given brightness and is therefore not quite as good for displaying large quantities of information. This is compatible with uses that employ red as an attention-getter for small but important messages such as error messages.

White is a combination of the three primaries and is therefore the brightest color available. This makes it suitable for emphasis, highlighting, and so on. Its achromatic quality also makes it suitable for use as a "monochrome" bright-up substitute. Good convergence is essential if large quantities of data in white are to be read by operators.

The B models of 3279 have seven colors and complete program control over their use on the screen. The seven colors are the four described above, plus turquoise, yellow, and pink. (Pink rather than "magenta" because of the desaturated blue.) These colors, being combinations of two primaries, are relatively bright, and the pink and turquoise are rather less saturated than the primaries.

An experiment in the Hursley Human Factors Laboratory showed that these seven colors are adequately discriminable and identifiable by color-normal observers, but the most common confusions were found to be between blue and turquoise and between white and pink. Confusions due to color blindness are discussed in Appendix 2.

Printer

The colors available on the IBM 3287 color printer are red, green, blue, and black. Although the first three correspond to the CRT primaries, there are noticeable differences, largely due to the change of background to white paper.

The color-coding implications of 4-color local printers are at present far from clear, particularly when they are to be used with 7-color display applications. In the simplest case, the printer will reproduce the four colors as they are arranged on the

screen, with black substituted for the display's white. There is little doubt that this should be the default situation when the printing is carried out independent of program control, and is exactly what is needed if the operator desires a local copy print to provide a record of what was on the screen. In other applications, however, if green (or blue) on the screen is used for "bulk" data it may be better if the colors do not correspond, black being printed for this data, especially if the printout and display are used separately.

The 7-color equivalent of this is more difficult because it necessarily involves a "translation" of yellow, pink, and turquoise into one or more of the four colors available on the printer. Although other translation schemes have been considered, human factors recommend that these colors default to black. This is in line with a general recommendation that any translations default to a neutral color, if available, and also fits in with the use of white/black as "nonspecific emphasis".

The reason for this default recommendation is that if colors have meanings to the operator, those meanings must be preserved and arbitrary color changes should be discouraged. If a color change is intentionally required for the application, then the program can make whatever translation is needed. This is likely to arise not only in the seven-to-four situation but also where the printout is used for a purpose different from that of the display, especially if its user is not the display operator. In this case the use of color should be chosen following an analysis of the user's needs in the same way as for the display.

When designing printouts in color, the characteristics of the colors produced should be borne in mind, as was suggested above for displays. Apart from black being available instead of white, the blue when printed contrasts well with white paper and green is no longer the strongest primary color. Therefore printouts that are not used together with the display may well use colors differently to achieve best effects. Printouts used with the display should however be consistent with the display's colors to avoid confusing the operator.

Appendix 2: Color Blindness

This section is intended to outline those aspects of color blindness that the application designer should take into account if the displays are likely to be used by operators with color-defective vision. A brief review of the incidence and nature of color-vision deficiencies is included, to give the reader an idea of the extent of the problem.

Incidence

The table below shows the percentage of males and females with congenital color-vision deficiencies. The different types of deficiency are explained below. The data are based on Judd and Wyszecki (1975) and agree in general with a number of other studies (see Robertson, 1976). The percentages are valid for populations of European origin only.

<i>Class of Deficiency</i>	<i>% Males</i>	<i>% Females</i>
Deuteranomaly	4.9	0.38
Protanomaly	1.0	0.02
Deuteranopia	1.1	0.01
Protanopia	1.0	0.02
Tritanopia	0.002	0.001
Monochromatism	0.003	0.002
Total	8.0	0.4

(The reason for the higher incidence in men is that the deficiencies are due to genes on the sex-determining chromosomes.)

Types of Deficiency

The normal eye has three types of light-sensitive cone-shaped receptor cells. These cells produce nerve impulses when stimulated by light and the brain interprets these signals to produce vision. The three types of cells have peak sensitivity at different wavelengths of light and a given wavelength will therefore produce signals of different intensity from different cells. The neural system can thus distinguish colors by comparing the outputs of different cells.

The three types of cone may be loosely referred to as blue, green, and red cones. A blue light stimulates the blue cones, a yellow light stimulates both the red and green cones, an orange light stimulates the red cones more strongly than the green ones, and so on.

If one type of cone is missing from the eye or not functioning then the brain cannot compare its output with the other two and therefore cannot distinguish all the colors that can normally be distinguished. If it is the red cones that are not functioning, this is known as protanopia, and if it is the green cones it is known as deuteranopia. (Tritanopia, the lack of blue cones, is extremely rare.) Together, these deficiencies are classed as *dichromatism* as opposed to the normal

trichromatism. If two or three types of cone are defunct the result is *monochromatism*.

In many cases, all three cones are working but one is weaker than normal. This is known as anomalous trichromatism, and depending on which cone-type is weaker is classed as protanomaly (red cones), deuteranomaly (green cones), or tritanomaly (blue cones). As the table shows, deuteranomaly is by far the most common type of deficiency. The anomaly varies in severity from person to person: in some it is so slight that they are not aware of it; in others it is almost the same as in a dichromat. The effects on vision of the anomalies are similar to but less severe than those of corresponding dichromacies.

People with protan or deutan deficiencies are often grouped together as "red-green deficient", because they tend to make similar confusions between red, green, and the intermediate colors (yellow, orange, etc).

Effects of Deficiencies

It must be understood that "color-blind" people *can* see and read characters in most colors. (Extreme reds or blues could cause some dichromats problems, but are avoided on many color CRT displays, including the 3279.) What the color blind may not be able to do is accurately identify the colors. As mentioned above, most difficulty will be encountered in the green-yellow-red area because green and red cone problems are the most common.

In some applications this inability to identify colors will not matter, either because color identification is not crucial or because the operator's decisions can be made on some other basis. Monochrome-compatible applications, for example, may benefit from added color without it being essential. Where color identification is crucial and color-deficient operators may be involved, the application designer should consider the aids below.

Aids to Color Identification

The following techniques can help those with color-vision deficiencies to use color displays with fewer errors of color identification. They will also help anyone viewing the display under demanding or difficult conditions.

- For important or common discriminations, avoid green/yellow/ red comparisons. Instead use yellow/blue, red/turquoise, green/pink, or on 4-color machines white/blue, blue/green, etc.
- Training, experience, and practice all help. The color-deficient operator can compare his own reaction with those of a color-normal operator.
- The operator can use other cues to identify the colors. For example, the brightness and saturation of the colors vary. Yellow, as a secondary color, has twice as many phosphor dots illuminated as red or green.
- Redundant coding, monochrome compatibility, and other characteristics of the picture can remove the need for color discrimination.
- Large, bright fields viewed with plenty of time will produce fewer identification errors than small transient fields at low brightness.

Summary

- Use a legend or key so that comparisons can be made: discriminating between two colors that are both visible is easier than identifying one without seeing the other.

Color blindness affects about 8 percent of men and 0.4 percent of women, that is probably less than 4 percent of operators. These individuals can still use multi-color displays, but may confuse certain colors such as green and yellow. The severity varies from person to person. Techniques to aid the color blind are suggested above.

Appendix 3. Example Figures

The following pages contain a small selection of example pictures to illustrate points made in the text. Please note that the color of the photographs does not accurately reproduce the screen colors, particularly in the toning example. The display from which the photographs were taken is an experimental device and the picture quality is therefore not representative of any IBM product.

FORM 2 DAILY SCHEDULE UPDATE
 TODAYS DATE: 143

DISTRIBUTION: PRODUCTION

JOB/NO	DATES		PART/NO	DESCRIPTION		COST	
	START	COMPLETE		QUANTITY	ITEM	PLANNED	ACTUAL
0254	151	159	01568	2000	BRACKETS	1.75	
0255	141	144	34527	0110	SPRINGS	0.54	0.54
0256	147	157	11372	9275	WASHERS	0.05	
0258	140	172	29442	0450	PLATES	3.65	4.02
0259	139	143	33477	0015	WIDGETS	1.25	1.22
0260	143	149	55286	0144	SPRINGS	0.54	
0262	154	160	22153	1000	BRACKETS	1.75	
0263	159	165	13457	2250	NUTS	2.25	2.25
0265	155	162	14435	0125	PLATES	1.34	
0266	160	173	22134	0235	WASHERS	1.44	1.24
0267	156	170	15850	0290	BOLTS	3.45	
0269	161	167	15784	0687	BRACKETS	0.75	1.00
0271	164	177	84356	0020	SPRINGS	0.75	
0273	162	175	56392	4500	PINS	3.75	3.75
0274	156	168	22153	0500	BRACKETS	0.85	

Figure 1. Production Schedule and Cost Display

This example shows a very simple use of color in a picture that could be used for two separate purposes. For the machine-shop foreman the most urgent job is emphasized by its contrasting color. For a user in the accounts department, however, this color emphasis draws attention away from the fields of most interest, where planned and actual costs do not match. This shows that there is no particular best way of using color; the needs of users should be carefully analyzed before the color codes are chosen.

CLEMIS POLICE REPORT

Period covered - From 08-01-79
Run Date: 09/03/79

MRS Report LPS 131M0

Appraisal Report For Badge No. 040

Selected categories	Total Items For Badge No. 040		Total Items For Department		Projected Distrib. For Badge No. 040		Performance Index For Badge No. 040	
	This Mo	Y-T-D	This Mo	Y-T-D	This Mo	Y-T-D	This Mo	Y-T-D
Dispatched Runs	88	579	2,854	20,387	66.45	495.48	1.32	1.17
Complaint Reports	61	397	2,357	17,479	54.88	424.80	1.11	0.93
Traffic Violation	11	151	713	5,604	16.60	136.20	0.66	1.11
Arrests - Felony	3	8	34	289	0.79	7.02	3.80	1.14
Arrests - Misdemean.	2	40	173	1,409	4.03	34.24	0.50	1.17
Arrests - Juvenile	2	9	42	307	0.98	7.46	2.04	1.21
Traffic Warnings	18	180	436	4,262	10.15	103.58	1.77	1.74
Building Checks	51	3,750	734	18,522	17.09	450.15	2.98	8.33
Local Ordinance Vio.	4	20	136	803	3.17	19.52	1.26	1.02
Service Requests	0	0	0	0	0.00	0.00	0.00	0.00
Field Interogations	0	0	4	19	0.09	0.46	0.00	0.00
Total Assists (Police & Fire)	37	294	1,237	9,936	28.80	241.48	1.28	1.22
Totals	277	5,428	8,720	79,017	203.04	1,920.41	1.36	2.83
							1.39	1.59
							0.97	1.01
Total Patrol Hours Of Officer			This Mo	Y-T-D				
			140.98	1,134.64				

Figure 2. Performance Record Display

Here the color is used to aid the formatting, and to emphasize exceptional conditions in the righthand columns.

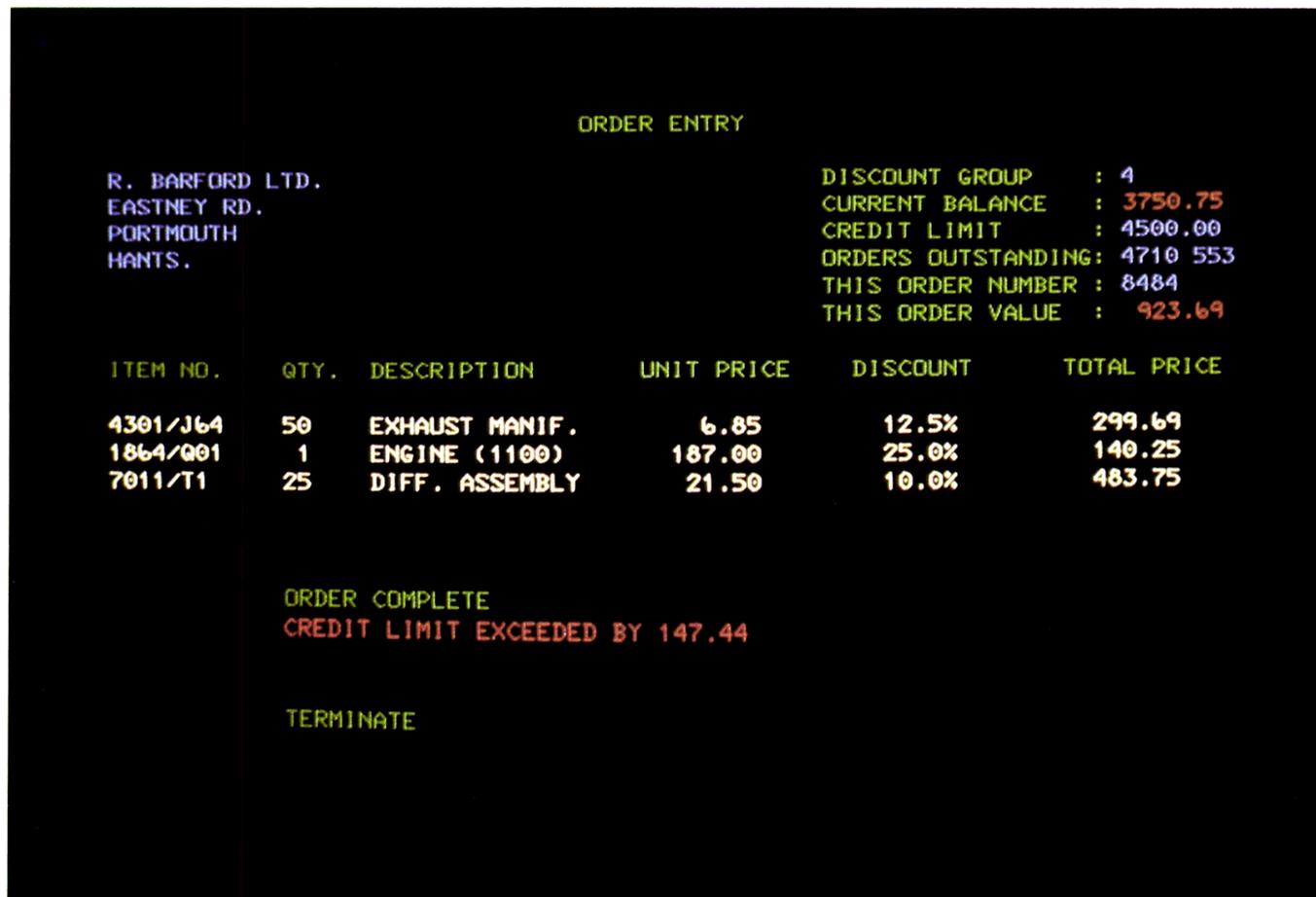


Figure 3. Order Entry Application

This figure illustrates the use of four colors in a straightforward alphanumeric application. The operator fills in an order form on the screen, probably while talking to the customer on the telephone. In this example the "boilerplate" or form is in green, the name, address, and billing information from the customer's file is in blue, and data entered during the transaction is white. Red has been used to indicate a problem and to relate the three fields on the screen that are associated with the problem.

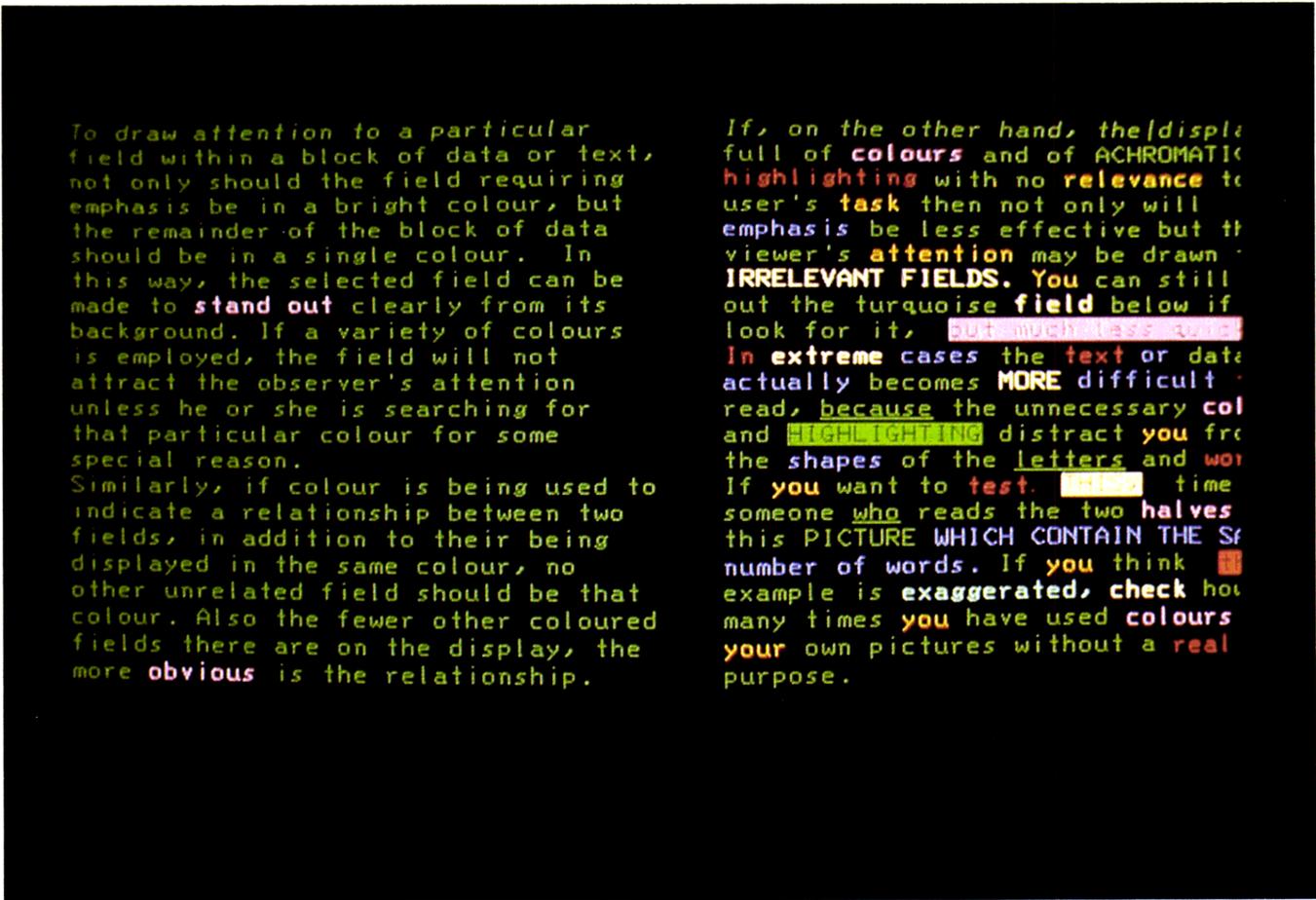


Figure 4. Emphasis and Overuse of Color

The text of the figure is self-explanatory. On the right, the overused irrelevant color and highlighting make the display very difficult to read and comprehend. Even where the color has some meaning, it stands out and can be found much more quickly in a "conservative" picture (as on the left) than when surrounded by many colors.

INCIDENT REPORT PART2 (LINES 08-17)

```

08  CODE      NAME: LAST, FIRST, M  ADDR  APT  CITY  STATE
    3135      TRIMNELL, JOHN, M  47    MEADOW GARDENS  TWYFORD  NJ
09  HOME PHONE  BUS PHONE  AGE  SEX  RACE  BIRTHDATE  DRVR LIC NO  STATE
    3278 33619  0962 4433  22  M    C    09 08 55  TR7915355J  FA
10  HGT  WGT  EYE  H:CLR-LGTH-STYL  BUILD  COMPXN  ID-ARREST  CHARG  FM  LR  HS
    5-08 145  BR   DARK-S-CURL      M/H    DARK    245-9771  235    Y  N  N
11  CODE  TYPE  YR  MAKE  MODEL  COLOR1  COLOR2  YR  ST  LIC-PLATE
    62DS  SALOON  76  PLYM  BARRACUDA  GREEN  PURPLE  77  NJ  421-7779
12  SERIAL NUMBER  VALUE  CONDITION OR OTHER ID
    000154732M76-1  450  CRASH DAMAGE LH SIDE
13  PROP TAG  VEHICLE LOCATION  LKD-KY-IN  OFF  DPT/PERS  DATE  TIME  LEO
    947-79  MEADOW GDS  Y  N  N  N/A  11 02 79  22 45  Y
14  CODE  TYPE  MAKE  MODEL  COLOR1  COLOR2
    62GV  LADIES  LEATHERTON  ECONOMY  RED  WHITE
15  YR  SIZE  SERIAL NUMBER  VALUE  PROP TAG  LOCATION
    78  ECON  N/A  25  949-79  STATION
16  CONDITION, CAL, SHOTS, BBL, LENGTH  DESCRIPTION-OTHER  ID  LEO
    FINE, 38, 2, 17  PEARL HANDLE  Y  Y

```

Figure 5. Poor Choice of Color and Formatting

In this case, the color code has been chosen to have some meaning to the operator but is somewhat excessive and has the effect of breaking up the already irregular formatting. A better approach would be to format the screen in blocks each dealing with a topic such as the person, the car, and so on. Color could then be used to accentuate the format on what is a fairly crowded screen, and to show relationships between items in different blocks if necessary. (In use, the screen format is constrained by the need for compatibility with a paper document.) See Figure 6 for an improved version.

```

                                INCIDENT REPORT PART2
NAME: FIRST, LAST, M
      : TRIMNELL, JOHN, M
B/DATE: 09 08 55
DV/LIC: TR7915355J

  ADDR: 47          CODE: 3135          CODE: 62DS          CODE: 62GV
  APT: MEADOW GDNS AGE: 22          HGT: 5-08
  CITY: TWYFORD    SEX: M          WGT: 145          COLOR1: GREEN      COLOR1: RED
  STATE: NJ        RACE: C          EYE: BR          COLOR2: PURPLE     COLOR2: WHITE

HOME   HAIR
PHONE: 3278 3361 CLR: DARK   BUILD: M/H   YR: 76          YR: 78
BUS    LGTH: S    COMPXN: DARK MAKE: PLYM   MAKE: LEATH/TON
PHONE: 0962 4433 STYL: CURL  MODEL: B/CQUDA MODEL: ECONOMY
                                     TYPE: SALOON  TYPE: LADIES

                                     LIC/PLATE: 421-7779  SIZE: ECON
                                     SER/NUMBER: 15473276-1 SER/
                                     YR: 77          NUMBER: N/A
                                     ST: NJ

ID-ARREST: 245-9771  PROP TAG: 947-79  PROP TAG: 949-79
CHARGE: 235          VALUE: 450       VALUE: 25

CONDN: FINE          VEH/          LOC: STATION
CAL: 38             LOC: MEADOW
SHOTS: 2            : GDNS
BBL: 17             :
LENGTH:            LKD: Y        CONDTN/
LEO: Y              KY-IN: N      OTHER-ID: CRASH
                   OFF: N          : DAMAGE ON
                   DATE: 11 02 79

```

Figure 6. Improved Color and Formatting

An improved version of Figure 5. The picture has been structured into blocks related to the logical divisions of the data, and the color has been used to enhance this formatting. Lining up the fields and separating field names and "data" help the operator to find items on the screen. The example is not intended as the best possible screen arrangement (a close study of the application being needed for this) but to show how simple changes can improve the clarity of a picture.

OPEN WORK ORDERS BY WORK CENTRE

PAGE:001

SHOP DATE : 134
 CAL. DATE : 08/06/77
 CENTRE : A02(AUTO LATHES)
 DEPT : 105

FROM W/C	ORDER NO.	PART NO.	OPER NO.	QTY.	SET UP.	RUN	STATUS	DATE
420B	212484	1727/401/10	010	2500	1.5	150	NR	133
420B	212317	2844/003/1	010	100	0.5	10	NR	138
184	212408	1740/400	020	1500	2.5	85	UA	140
185	212421	1932/650/00	010	250	0.5	20	SU	140
419	212308	2121/00	030	1850	0.5	110	UA	146
041	212309	9845/225	020	5100	1.5	350	NR	130
098A	212470	7131/000/1	010	250	0.5	18	SU	138
231	212434	2015/938	080	300	2.5	15	SU	138
231	212310	3000/180/02	040	2000	0.5	95	AS	134
231	212620	3000/180/02	040	150	0.5	10	UA	135
144	212297	2244/1	060	2400	2.5	125	AS	139
145	212188	1090/722/30	010	750	0.5	30	NR	138
207	212500	4505/21	020	800	1.5	30	UA	140
330	212510	8448/22/10	010	500	1.5	25	AS	142

OVERDUE NO SLACK OTHER

Figure 7. Simple Status Coding

In this example, color is used to pick out the most urgent jobs awaiting completion at a particular department in a machine shop. The color code allows position (that is, order of the list) to be used for other purposes. Note that the two levels of severity are coded in red and pink (similar colors) and are explained by a small legend at the bottom.

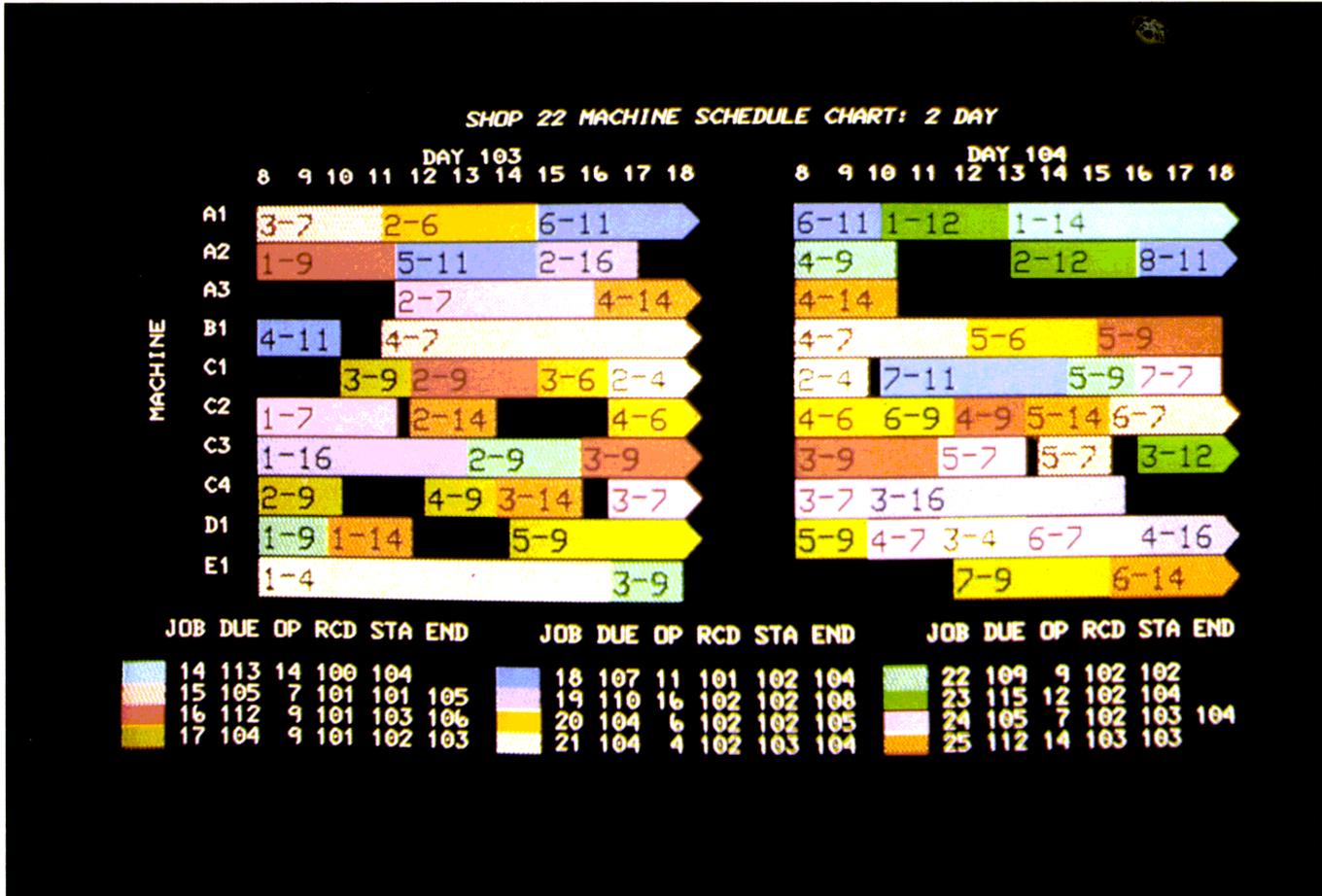


Figure 8. Graphic Machine Tool Schedule

This display could be used in the same environment as Figure 7. The scheduler uses it to assign particular stages of jobs to machines in order to meet the jobs' schedules and to maximize machine usage. This picture uses twelve color tones to code the jobs plus white (and black) alphanumerics. The tones are shown in the legend, and were chosen from the set of 64 available in GDDM.

Glossary and Abbreviations

Achromatic: without the quality of color.

Base color: the A models of the IBM 3279 select the color of the field being displayed by taking the bits in a monochrome 3270 data stream which usually select high intensity ("bright-up") and protected/unprotected and interpreting them as green, blue, red, and white (for normal intensity/unprotected; normal intensity/protected; high intensity/unprotected; and high intensity/protected respectively).

Boilerplate: the fields in a display picture that do not change during the transaction conducted with that picture. Usually the headings of columns, field names, and the like.

Chromaticity: the exact technical specification of a color, including its hue and saturation. The CIE (International Commission on Illumination) produces standard chromaticity-specification systems. (See References.)

Coding: in this report, indicating to which of a set of categories an item of data belongs by means of an identifier such as a color, a symbol, a highlighting mode, or any other visually recognizable signal.

Color triangle: a means of representing colors in a two-dimensional plane, usually with hue being specified circumferentially and saturation radially. For example, the three corners of the triangle would be red, green, and blue, with white at the center and secondary colors along the sides.

Cone: a type of light-sensitive receptor cell in the retina that allows color vision.

Contrast: the degree of visual difference between an item and its background or surroundings. Usually the brightness difference between a character and the screen that allows the visual system to perceive the character.

Convergence: the exactness of the registration of the primary colors producing a secondary color at any point on a multicolor CRT screen. On a well-converged screen, the red and green components of a pel are in exactly the same place, producing a yellow pel. On a misconverged screen, the red and green components are not properly aligned and the result appears as either separate red and green pels or as a yellow pel with red and green fringes.

CRT: cathode ray tube. An electronic vacuum tube that is used to display pictures containing alphanumeric, text, graphics, or images in VDUs.

Cyan: the name usually used by technologists for the color produced by mixing blue and green on a color CRT. Called turquoise on the IBM 3279.

Desaturated colors: colors with low saturation, that is, a high proportion of white with the dominant hue. Pale or pastel colors. See also Saturation.

DP: data processing.

Ergonomics: See Human factors.

Expectancy: in this report, the preconceived interpretation of the meanings of colors formed from the observer's associations and experience of the use of color outside the application in question.

Fill pattern: a predefined pattern used to fill an area of the picture on the display. For example, cross-hatching or toning.

Flicker: An undesirable visually apparent brightness pulsation of a VDU picture or part of a picture.

GDDM: IBM Graphical Data Display Manager, a program product that uses the Programmed Symbols feature of the IBM 3279 and other devices to construct and display graphics pictures.

Hue: that aspect of color determined by the wavelength of the light being observed and differentiated by terms such as "red", "blue", "yellow", etc.

Human factors: in this report, the study of man in his working environment and the application of the knowledge gained to the design and use of equipment with the objectives of improving the safety, comfort, and satisfaction of the operator and the efficiency of the man/machine system. Effectively synonymous with ergonomics.

Interlace field: on many CRTs, the electron beam that produces light when it strikes the inside of the screen is scanned across the screen in horizontal lines, one below another. On an interlaced display, the beam scans the odd-numbered horizontal lines from the top to the bottom of the screen and then the even-numbered lines from top to bottom before returning to the odd-numbered ones again. Thus the screen is refreshed in two fields, one containing the odd lines and the other containing the even lines.

Magenta: a purple color normally produced by mixing red and blue on a CRT. Replaced by pink on the IBM 3279.

Migration: in this report, changing the device that an application or user employs, usually moving to newer machine types as they become available or as the application requires them.

Monochrome: of a single color.

Monochrome mode: a status of a multicolor display device where it acts as a monochrome display. In the case of the IBM 3279 in monochrome mode, all fields are displayed in green unless the program selects them to be "intensified", in which case they appear in white.

Multidimensional coding: coding where the category or categories of the data being coded is indicated by codes of more than one type. For example, color and position are both used to identify the signals in traffic lights.

Pel: picture element, the smallest addressable area on the screen, equivalent to one of the dots that make up characters on the display.

Primary color: on a CRT, one of the three colors (usually red, green, and blue) that are activated by a single electron gun and are not produced by combining other colors.

Protanope: one type of color-blind person. See the appendix on color blindness for a fuller explanation.

PS: Programmed Symbols, a feature on the IBM 3279 and other devices that provides user- or software-definable characters to be displayed. This allows the construction of graphics character sets or special alphanumeric fonts such as italics.

Redundancy: when the same information is displayed or transmitted by two or more different codes, they are said to be redundant. When two coding dimensions code different information, they are nonredundant.

Retina: a multilayer light-sensitive membrane on the inside surface of the eye that is connected to the brain by the optic nerve.

Reverse video: displaying characters in reverse polarity, that is, with unilluminated pels showing the characters' shape against a background of illuminated pels. For example, black on green instead of green on black.

Saturation: vividness of hue; a quality of color related to the range of wavelengths in the light being observed, or to the degree of white in the color. For example, CRT red is saturated, white is completely unsaturated, and pink is of medium saturation. The characteristic commonly differentiated by words such as "pale", "deep", "pastel".

Secondary color: a color produced by combining two or more primary colors. On a seven-color CRT display the secondary colors are usually yellow, turquoise (or cyan), pink (or magenta), and white. For example, yellow is the secondary color produced by combining red and green. Note that this applies to displays emitting light, not ones such as printers that work by reflecting light.

Staircasing: an effect where sloping lines are stepped rather than straight, because points nominally on a straight line can be represented only by energizing the nearest pel.

Subject: in this report, a participant in a human factors experiment or study.

Toning: creating areas on the screen that have a proportion of the available picture elements illuminated. A greater proportion of on-pels in a given color makes that color in the toned area appear brighter. Varying the number of on-pels (or apparent brightnesses) of two or three primary colors in one area creates a range of apparent colors available in the area that is greater than the number of colors that is achievable in a single pel.

Translation: displaying an item of data in a color other than that selected by the program, usually because the device cannot produce the color selected.

VDU: visual display unit.

Word profile: the shape of a word created by the ascending strokes and descending strokes of lowercase letters. The profile assists legibility by giving cues as to the identity of the word.

3270: the IBM 3270 Information Display System. A family of IBM VDUs and associated control units and printers.

3277: the IBM 3277 Display Station: a monochrome VDU.

3278: the IBM 3278 Display Station: a monochrome VDU.

3279: the IBM Color Display Station. A multicolor VDU with the following models: 2A displays 1920 characters in four colors, 2B displays 1920 characters in seven colors, 3A displays 2560 characters in four colors, 3B displays 2560 characters in seven colors. The A models use the base color system.

3287: the IBM Printer: a monochrome or multicolor printer associated with the IBM 3270 system of display terminals.

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