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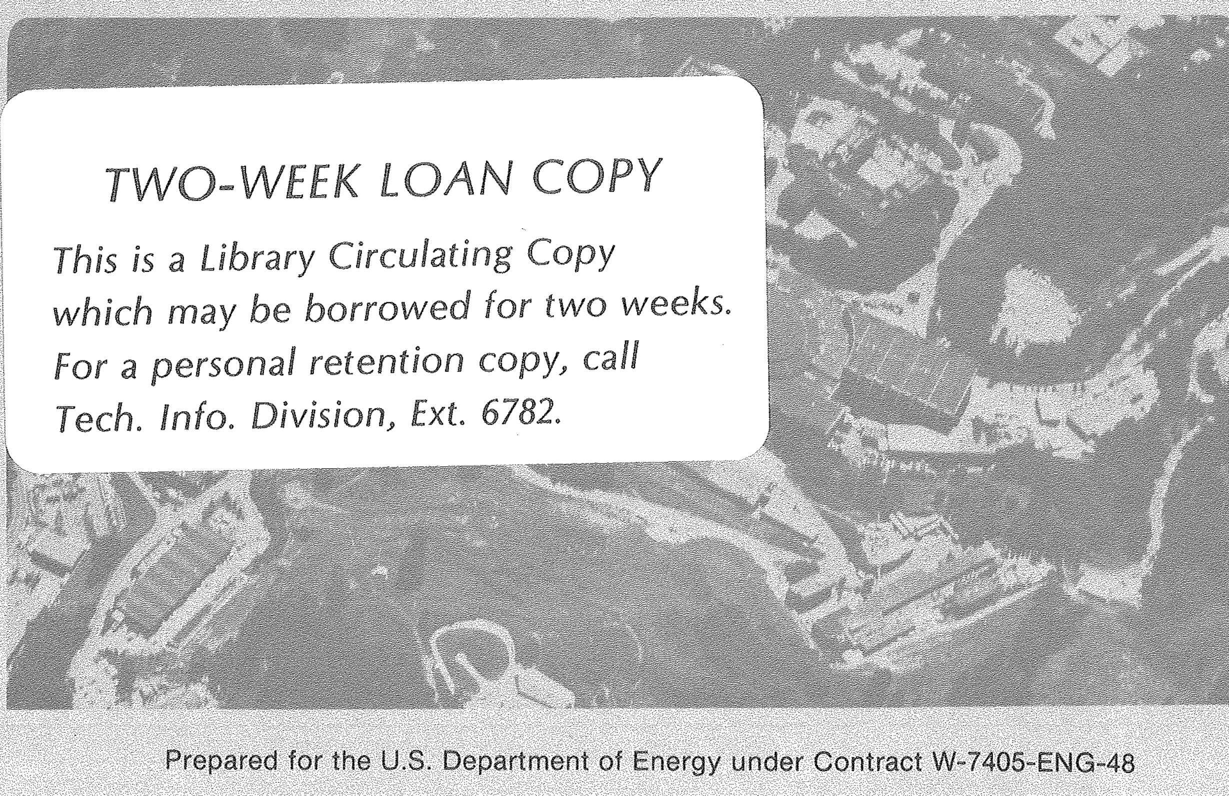

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COMPUTER-ASSISTED CHART MAKING
FROM THE GRAPHIC DESIGNER'S PERSPECTIVE*

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Abstract

It is important to improve the aesthetics and effectiveness of information graphics through greater awareness of graphic design as a visual communication discipline. Chart making is one subject area in which graphic design awareness can be enhanced. Basic design principles are reviewed which are relevant to creating better charts. Examples demonstrate improvements.

CR Categories: 3.19, 3.29, 3.39, 3.49, 3.59, 6.69 3.79, 3.89, 3.9, 8.1, 8.2

Key Words and Phrases: charting, computer graphics, graphic design, effective data displays, display design principles, visual data encoding, human factors.

Introduction

After two decades of development from the simplest typographic display equipment, computer graphics is entering a decade of visual sophistication. In the "Information Age" of the 1960's and 1970's, society witnessed a proliferation of data gathering, processing, and distribution techniques. As the "Image of Information Age" evolves, researchers, policy makers, and the general public are realizing more clearly that human beings cannot effectively utilize large quantities of computer-processed information for making decisions, for becoming informed, or merely for perusing data. Technical achievements appear to surpass the actual quality of imagery in terms of conveying information through innovative forms and exhibiting sensitivity about aesthetic issues in communicating information graphically. There is clearly a need for converting vast amounts of numerically stored data into spatial (sometimes geographical), temporal, and colorful forms so that significant patterns emerge from informational graphics, particularly, charts, maps, and diagrams.

Many computer graphics advertisements and much professional literature exhibit charts, maps, or other diagrams. If one examines these carefully with an eye trained in visual communication, one notices oversights or errors in visual thinking which seem clearly unintended, such as color combinations that inhibit legibility, poor typographic hierarchies, or confused composition. The situation is often not the result of deficient equipment but simply the result of computer graphics displays created by persons with relatively little training in graphic design, i.e., in typography, color, composition, non-alphanumeric symbolism, photography, and reproduction processes.

The ignorance of the computer graphics world about the world of graphic design will probably disappear in this decade. Computer graphics professionals will seek the principles of effective design of informational graphics. Unfortunately, there is far less research into legibility, readability, and aesthetics of effective charts, diagrams, and to some extent maps, than there is in terms of conventional linear texts for books, magazines, and newspapers. There will probably be increasing pressure to convey information through non-linear spatial arrays of symbols. [1] In this environment, a mutual interchange of expertise and interests between computer graphics and graphic design may generate more effective research into information graphics and eventually may yield higher quality displays, where quality signifies more than technical achievement.

An intention of this paper is to begin to bridge the gap between computer graphics and graphic design by outlining some principles of effective graphic display of information, beyond the general ideas mentioned in Morse [1979]. There is no definitive manual on informational graphics. There are some texts on the design of charts, diagrams, and maps [2] but these suffer from several limitations: they are often out of date in terms of media and stylistic qualities of imagery; they are sometimes too casual in presenting specifications for information display; and they

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are occasionally in disagreement with regard to specific recommendations [3]. One unusual book edited by Herdeg [1979] entitled Graphis: Diagrams offers a startling array of possibilities for chartmaking and diagramming at the highest level of artistic quality. However, it offers very limited information concerning the context from which each diagram emerged, how other similar diagrams might be designed, and how successful the diagrams were. Nevertheless, it demonstrates the levels of visual sophistication which computer-assisted informational graphics might achieve with the addition of the graphic design dimension.

This present article emphasizes aspects of computer graphics displays that enhance the ability of human beings to recognize, comprehend, and remember information. The discussion also concerns factors that contribute to the user's enjoyment or interest in examining data. These are not insignificant aspects: the pattern recognition equipment for informational graphics is the human visual system, not an electro-mechanical device. The difference between these two is equivalent to a distinction between readability (qualitative phenomena promoting alertness, receptiveness, and interest) and legibility (quantitative phenomena aiding discernment of discrete units or segments of information). From a graphic designer's point of view (the author's), the discussion in this article is meant to focus not on questions of style or taste but upon fundamental problems of visual thinking. For the most part the comments are intended to enhance ideas about default displays of computer-assisted charts, one of the most common means of displaying data on a computer graphics system.

Principles of Visual Communication

Effective visual communication is based upon wise application of principles of visual organization and quantitative limits to perception. These principles are fundamental to any discussion of symbols in space, of their figure-field relationships, movement, implied depth, or overall compositional scheme.

In the early twentieth century, Gestalt psychologists isolated several principles of visual organization. During the intervening half-century these principals have been rephrased and re-emphasized, but they remain essential categories of great usefulness. One researcher who formulated a careful list was Wertheimer [1939]. His set of principles include the following. Each is illustrated with simple visualizations, for which correlates in charting can be found. One such example is given for the first entry.

Proximity: objects seem to belong together because of their location in space. An example from charting would be the face that lines of closely spaced type in the same size appear to group together. The natural grouping unit is ab, not bc.

```
ab    cd    ef    gh
..    ..    ..    ..
```

Similarity: objects seem to belong together because of their visual properties such as shape, size, color, orientation, and texture. The natural grouping unit is ab, not bc.

```
a b c d e f g h
x x . . x x . .
```

Note that two principles, e.g., similarity and proximity, may be combined into pro-structural and contra-structural grouping.

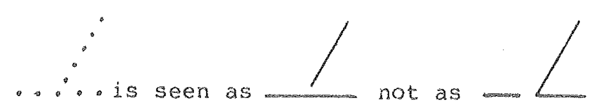
```
x x     . .     x x     . .    pro
x    x .    . x     x .    .   contra
```

Common fate: Changes in an already established set of objects conform to grouping already evident.

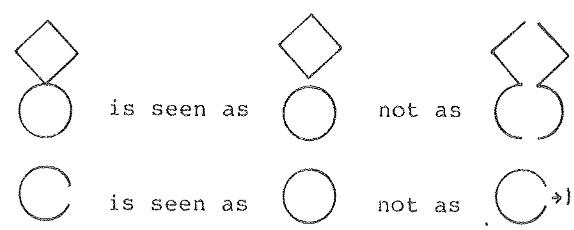
```
. . .   . . .   . . .   . . .    given

. . .           . . .   . . .    pro
        . . .

. .         .   . . .   . . .    contra
    . . .
```

Objective set: within a spectrum of states of an object, condition, or grouping, certain ones seem stronger or more objectively basic. For example, a nearly-right angle is seen as a right angle.

Direction: objects are seen to belong together because of their unified direction even in contrast to proximity.



Closure: objects are usually seen as self-enclosed simple wholes.



Although the human visual system is an enormously sophisticated pattern recognition device, it does have clear limits to its perception of visual phenomena. Of relevance in this discussion are various changes in color, line weight, and other elements typical of chart-like information displays. These factors are discussed in Martin [1973, Chapter 21] and also by Foley and Wallace [1974 p. 464] whose comments follow:

"The perception of structure among objects can be enhanced by using different line types (solid, dotted, dot-dash), widths, intensity levels, or geometric shapes. These all help make a display more meaningful....[Other] references provide more specific information concerning the usefulness of various distinguishing features, [and they are cited] in Table I. For each technique, the number of easily distinguished codes is listed. They are listed in approximately decreasing effectiveness, with color providing the most useful distinction. It is relatively expensive, however, and unacceptable for the color-blind [viewer]. The other techniques are often available inexpensively...."

Table I

Coding Method	Maximum Number of Codes for Essentially Error-Free Recognition by Normal Individuals
Color	6
Geometric Shapes	10
Line width	2
Line type	5
Intensities	2

Sources: J. Martin, Design of Man-Computer Dialogues, Englewood Cliffs, N.J. Prentice-Hall, 1973; and J. Barmack and H. Sinaiko, "Human Factors Problems in Computer-Generated Graphic Displays," Inst. for Defense Analysis Study, DFSTI ASTIA Doc. AD636170, Vol. 5-234, April 1966.

The Graphic Design Perspective

These principles of visual organization and limits of perception form a conceptual basis for the grid-oriented or so-called Swiss approach to graphic design. It is an approach eminently suited to information display in which many complex relationships must be distinguished carefully and clearly.

The Swiss approach to graphic design derives from the German Bauhaus and the Russian Constructivist artistic trends of the early twentieth century which emphasized functionalism, new technology, and rationalism. The Swiss approach to graphic communication as seen in posters, books, magazines, diagrams, etc., emerged in a clear form during the 1950s and early 1960s. Swiss graphics had a world-wide impact upon graphic design curricula. It also took hold in offices of major international corporations which adopted the principles for the business world because they could be relatively clearly and precisely formulated. This approach to graphic design could account for the myriad of visual forms which any large corporate entity or institution wanted to include in its visual identification. Presently the National Endowment for the Arts' Design Excellence Program is seeking to develop the use of the Swiss approach in governmental publications [Blackburn, 1977; Vignelli, 1977].

It is not without significance that Swiss graphic design is called programmatic design [Gerstner, 1968]. In theory a significant number of quantifiable attributes of the finished visual design can be traced to a list of needs with priorities. In effect syntactic conditions can be clearly traced back to semantic relationships, to use the terminology of visual semiotics, the science of signs and meaning [Eco, 1977].

The general visual characteristics of Swiss-oriented graphic design principles can be categorized in the following list [Marcus, 1971; adapted from Hyder, 1970]. While originally intended for a description of printed poster designs of the 1960s, these observations are now appropriate to mention as principles which are helpful for the display of information through computer graphics systems, whether printed on paper or appearing on a display screen.

Sans Serif Type Styles: Following the precedent of the Bauhaus and the Constructivist typographers, the Swiss designers rejected the traditional serif letters in favor of the more simplified sans serif letterforms (Fig. 1).

In 1957 Swiss designers introduced two new sans serif typefaces, Helvetica and Univers (Fig. 1). Because of their frequent use in graphic design work influenced by the Swiss approach, Helvetica and Univers have become strongly associated with the Swiss typographic style. Both typefaces retain the 'machined' look and the uniform letter weight that the rougher versions of the 1930s introduced, but add a greater homogeneity and a new elegance to the curves used in their letterforms. These two faces remain standard typefaces for modern, clear typographic displays.

Simplified Imagery: The standardization of format for Swiss posters prevented the poster designer from relying on the size of the poster to gain impact. Instead, the designer had to work from 'effectiveness at a distance which belongs to the mural rather than [the easel] painting.' [Von Grunigen, 1968, p. T-45]. This contributed greatly to an early universal reduction in the amount of primary text presented on a poster as well as the use of one essential image for immediate recognition.

The typographic emphasis of the Swiss poster asserted both the usefulness and the sufficiency of typography alone to attract the eye of the viewer and to communicate, through the basic text of the poster, other abstract symbolic meaning. For such strict advocates of typographic design for posters as Ruder [1967], imagery was usually limited to typography. When illustration was included it was often geometrical in form. When photography was introduced it was usually treated in scale (e.g., greatly enlarged size) or in tonal emphasis (e.g., high contrast photographs) so as to immediately simplify the image. In conformity with the choice of modern typefaces, the imagery of Swiss design emphasized reduced complexity, flat surfaces, and images that were technically transformed, without traces of manual operations. 'Hand-drawn' images were generally excluded.

Open Spaces: Within the simplified image of the Swiss poster, carefully used negative spaces devoid of both text and illustration establish a geometric subdivision of the poster's field or provide emphasis for the visual elements within the poster. Given a fixed format, a limited set of typographic elements, and often no other imagery than type, the designer must rely essentially upon spatial composition to make the informative aspects of the poster clear and to provide the arena for provocative aesthetic relationships.

Consistency of Design: No mixing of typefaces within a poster is one immediate result of a desire for simplicity. On the other hand, a variation within one type family (bold, medium, or light; condensed, regular, or expanded letterforms) can occur because of the uniform aesthetic features within a type family (Fig. 1). The number of these changes (in size, boldness, or proportion of the type) is usually limited to two or three. The proportion of these changes is usually a simple and dramatic factor. For example, for the proportional size of primary to secondary type, ratios of 2:1 or 3:1 are commonly found.

Strong reliance on a grid of implied lines that organizes and controls the positioning of typographic and illustrative elements also typifies the Swiss approach. The grid limits the horizontal and vertical intervals and establishes a series of harmonic visual relationships that make coherent the entire field of the poster.

The grid is also related to the proportions of the entire visual field. In other words the visual composition conforms to the available display field conditions. A rectangle of the proportions of one: square root of two (1:1.414) is the basic Swiss poster format and also the established norm for the European international paper size system. Within this rectangle lies the primary form of the generating square (Fig. 1) which is often used as an immediate source of asymmetric division of the field. Primary visual elements can be made to express directly or to imply this basic geometric relationship. For example, the location of a primary lext line might align with a major grid line. Such alignments help to integrate the composition. In some cases, such as in the work of Muller-Brockman, [1968] grids are created that can be used for a series of similar compositions. The grid provides many possibilities for the positioning of visual elements, allowing strongly differing variations to occur that are nevertheless clearly related visually. This approach is especially appropriate for chart making because typically many nearly identical charts are produced by any one system.

<u>An Example of Chart Development with Graphic Design Assistance</u>

The examples of Figures 2, 3, and 4 demonstrate the effect of applying graphic design considerations such as those principles mentioned above on a typical graphic display (Tektronix and Varian hard copy devices). The examples are intended to demonstrate improvements under the most wide-spread conditions of black-and-white, static images with simple lettering.

The displays were all created by CHART, an interactive chart making program developed at Lawrence Berkeley Laboratory's Department of Computer Science and Applied Mathematics for the SEEDIS project (Socio-Economic-Environmental-Demographic Information System) [Benson, 1976]. The program is similar to other commercial and in-house systems now in use in some businesses, government agencies, and research laboratories. An attempt was made to create a superior, more effective image using standard equipment and simple graphic techniques which would become default options for CHART. This section discusses some of the changes that were made in the charts and the reasons for these changes. By presenting this comparison, it will be possible to demonstrate more clearly the meaning and validity of the graphic design principles mentioned earlier.

An exemplary chart (Fig. 2) exhibits typical errors of basic design principles such as those discussed earlier. These oversights may be grouped into three general categories: syntax, semantics, and pragmatics. These categories of visual semiotics will be discussed below in the order mentioned. The definitions as presented here are brief, convenient ones suited for the context of chart making. For more extensive discussion, see, for example, Marcus [1978] and Eco [1976].

Visual syntax refers to qualities of the arrangements of letters, lines, and other symbols. One obvious characteristic of the chart information display shown in Figure 2 is that it has no visual limit, i.e., border. The total composition is vaguely organized around a central space of information, the chart itself. Another distinctive quality is that titles, outlines, chart lines, and alphanumerical labels are all relatively equal in weight, i.e., no particular item stands out from the others. In relation to the underlying grid of the chart space, the location of labels and the quality of lines is confusing. Note, for example, that horizontal and vertical lines are variously solid or dash-dot. The special quality of the 'PROJECTED NORMAL' chart line is not clear. Sometimes labels are centered on visible or implied lines and sometimes they are aligned along an edge.

In the revised chart style of Figure 3, the outline of the total space is explicitly stated so that all figure-field relationships are clear. The overall proportion of the chart has become decisive: 1:1.5. There is also an attempt to isolate the central chart space itself by gray levels from the surrounding information support space. Greater organization of all typography is apparent. The titles and labels are more strongly related to the basic charting area by alignment along an edge rather than a more vague central axis. There is greater differentiation (i.e., visual hierarchy) in use of line. Lines of type vary in size, and chart lines vary in thickness. Even within the gray area, a line of differentiation distinguishes past fact from future prediction. The chart 'whiskers' have been removed from the central chart space in order to reduce the clutter within the primary information space. Wherever possible, simplification and stronger organization have been stressed by coherent application of the principles of visual organization mentioned above. Similar things are identified in similar ways, and positioned to make visual hierarchy clear.

Visual semantics refers to the relationship between signs/symbols in the chart and the information to which the chart refers. One of the outstanding semantic features of the original chart of Figure 2 is the very high precision that is implied by the very thin chart lines. It is not necessarily the case that information is so precisely known. Another peculiar feature is that the chart lines are very precise, but the labels are not. This suggests that there is a discrepancy between the simple graphing of data and the intended reading of the overall trend or significance of the chart.

In the suggested revisions of Figures 3 and 4, several alternatives are suggested. Instead of individual error flags for data points, an envelope of relative certainty is created in Figure 4 by simply changing the background gray levels. In Figure 3 the lines themselves are now more clearly distinguished from grid lines, and the thickness of lines is more clearly related to the precision suggested by the labels. In general, visual emphasis through larger type, heavier lines, and gray levels is given to the more important items of the chart. Even this simple semantic relationship is sometimes inadvertently violated by many chart makers.

Visual pragmatics refers to the technical conditions and characteristics of producing charts, and to the human factors related to their being read by human beings, not machines. The chart of Figure 2 was produced with clear limitations in variation of line weight and texture, typographic style (e.g., no lowercase letters and unvarying character widths) and gray levels. These limitations obtain in many commercial display systems, although it is to be expected that future equipment will be more sensitive to the value of graphic variables. The other kind of pragmatic factor is exemplified by the conditions of Figure 2 in which the 'PROJECTED NORMAL' line is very hard to distinguish between grid lines and boundary outlines. Similarly, in terms of titling and labels, key words of the title are difficult to determine from the titling cluster. The changes which have been made in Figures 3 and 4 are intended to demonstrate that with even limited resources it is possible to make significant improvements in the appearance of information. These changes result in making the chart more readable as well as legible. Variations in typography through grouping, boldness, and size change have been used to make primary key words and phrases more identifiable. The chart 'invites' a viewer to examine information and is at the same time responsible to its content.

One other pragmatic aspect may not be readily visible to a casual viewer examining such displays: the problem of reproducing and of transfering the image of data for presentation as article illustration, overhead projection image, slide lecture image or poster seminar illustration. Such transformations are often done casually even though the images are not well designed for such charges. The scale of typography, the chart lines, and the general visual hierarchy exhibited in the original chart Figure 2 are not suited for most of the above uses except as a publication image of approximately original size (about 15 cm x 15 cm) Any significant reduction in size of the image might require its typography and even its lines to be redrawn by hand by a trained technical graphics person, thereby reducing the cost-effectiveness of the computer-assisted chart making. Even conventional xerographic copying of the original image would very likely make labels, footnotes, even primary titles illegible. In some cases crucial information could easily be lost.

The revised images are intended to be more useful as slide and poster images. The border proportion has been selected to easily accommodate typical paper and film proportions. In addition, Figures 3 and 4 are now designed to allow significant change in scale without harm: they can be enlarged to become primary visual images for an exhibit or can be reduced to become secondary, clearly articulated evidence for an article.

At some future time, a skillful algorithm in a truly well-designed computer graphics system might be able to accept input concerning the eventual use of the image (e.g. as a xerographic print, a 4-color high-quality lithographic image, or as a lecture slide image) and automatically compensate for necessary changes of typesize, line weight, texture, and conversion from/to color/black and white, etc.

Conclusion

The above discussion has introduced some basic graphic design principles which are relevant to the display of information graphics. The example shown presented a modest set of improvements for the creation, distribution, and consumption of information through computer-assisted chart making.

The initial efforts hae focused specifically on types of hard copy display equipment which have a limited graphic flexibility. Further developments need to be made to design better coordination of typography, line weight and texture, gray level, and symbol use among line charts, bar charts, pie charts, and maps. Wherever more sophisticated typography, gray values, color, and symbol presentation are functioning, even greater benefits can be expected from applying awareness of informational graphic design principles to the technical capabilities of computer graphics display equipment. It is hoped that this presentation will encourage greater attention on the part of the computer graphics community to the potential contribution of graphic design to more effective visual communication of information.

Acknowledgements

The author wishes to thank Mr. William Benson of the Computer Science and Applied Mathematics Department at Lawrence Berkeley Laboratory for his assistance in reprogramming CHART to create and display the examples shown with the text.

Footnotes

1. For a discussion of trends in typography and graphic design in the age of computer graphics, video and film see Marcus [1977].

2. For texts specifically on the design of charts, diagrams, and maps, see Schmid [1979], Spear [1978], Meyers [1970] and Robinson [1978].

3. Spear [1969,p.163] advocates bar charts with spacing between columns of one-half the width of columns, while Meyers [1970, p.96] suggests that for a number of bars in a relatively small rectangle, a space of one-third is appropriate.

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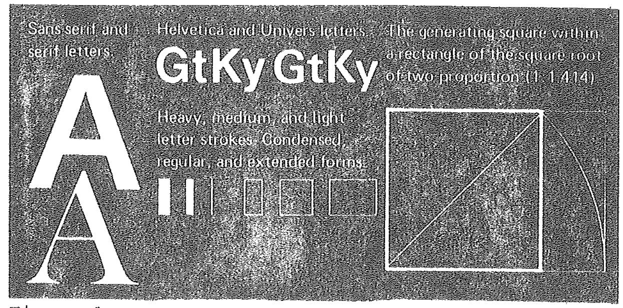

Figure 1

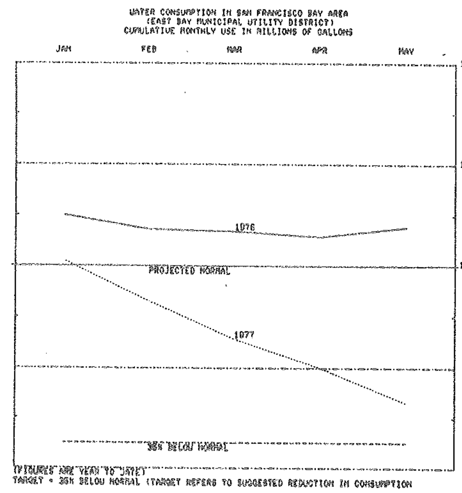

Figure 2

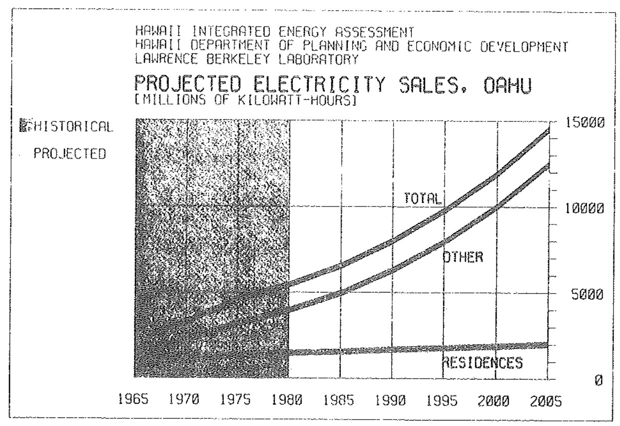

Figure 3

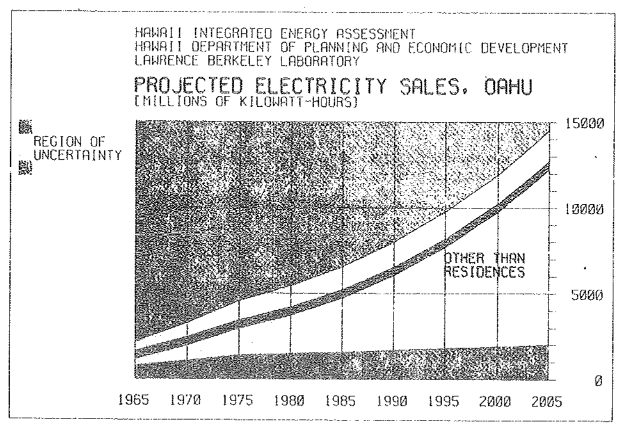

Figure 4