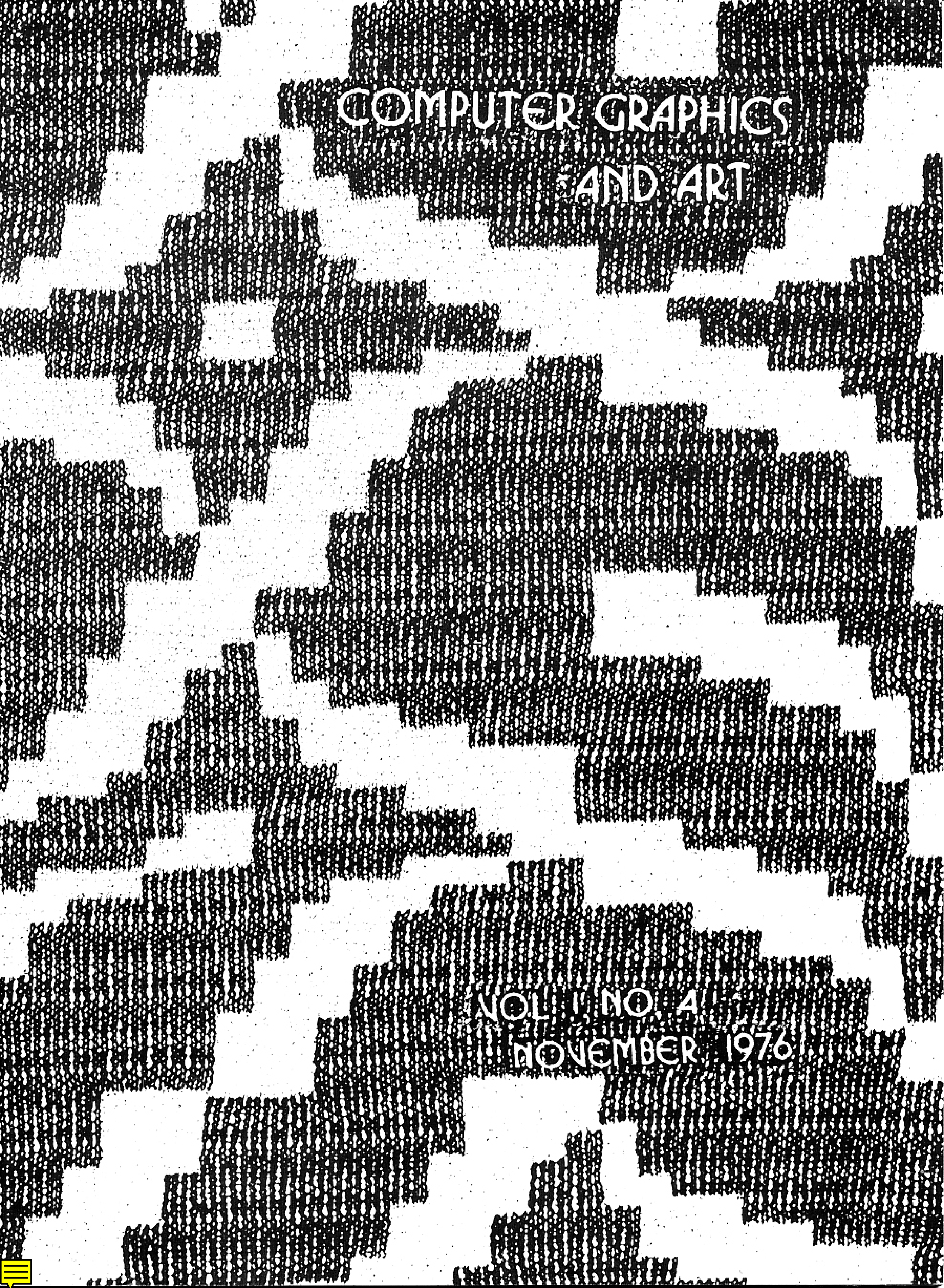
COMPUTER GRAPHICS
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VOL. 1. NO. 4 NOVEMBER, 1976 COMPUTER GRAPHICS AND ART

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NOVEMBER THEME: APPLICATIONS

Announcements

SIGGRAPH '77

The Fourth Annual Conference on Computer Graphics and Interactive Techniques will be held July 20 - 22nd, 1977 at the San Jose Hyatt House in San Jose, California. The conference is sponsored jointly by ACM/SIGGRAPH.

SIGGRAPH '77 will focus on research, applications and education in computer graphics and interactive techniques. Papers are solicited on a variety of topics, including graphical theory and techniques such as languages, hardware, software, tools, portability, standards, device independence, line graphics, raster graphics, data structures, satellite systems, human factors; applications in the area of environmental, urban, transportation, cartography, biomedicine, animation, computer aided design, art, music, business, statistics, recreational graphics, decision making, and computer graphics education.

Papers may report original work, unusual or unique applications or techniques of computer graphics, or they may evaluate graphical specifics.

Readers are invited to submit papers to the program chairman:

James E. George
Los Alamos Scientific Laboratory
P. O. Box 1663, MS 272
Los Alamos, New Mexico

ABSTRACT DEADLINE: A short abstract is requested by December 1, 1976 and the final paper must be submitted by May 2, 1977.

The General Chairman is Stephen Levine, Lawrence Livermore Laboratory, P. O. Box Livermore, California, 94550. He may be reached for further information at (415)447-1100, Extension 3360.

POSITION WANTED IN GRAPHICS

Dedicated graphics specialist looking for position in research and graphics development. Masters Degree in Computer Science (California State University, Chico), with doctoral study at the University of California, Irvine. Additional graphics research at University of California, Santa Barbara.

Thesis: "CHIC - A General Purpose Computer Graphics Language."

Experience with programming in FORTRAN, BASIC, ALGOL, LISP and varied ASSEMBLY languages. Currently working on two interactive graphics systems. Would like to expand them and/or do developmental work on other graphics systems.

CONTACT: Steven Williams
1225 Nord - #1
Chico, California 95926
(916)345-0292

THIRD INTERNATIONAL CONFERENCE ON COMPUTING IN THE HUMANITIES, AUGUST 2-5, 1977

The Third International Conference of CHUM will be held in Waterloo, Ontario, Canada from August 2-5, 1977 at the University of Waterloo. The conference is sponsored by the University of Montreal and the University of Waterloo.

For further information, write:

Professor J. S. North
Chairman, ICCH3
Department of English
University of Waterloo
Waterloo, Ontario, Canada

3 CIIH ICCH

NCC 1977, DALLAS, TEXAS - JUNE 13-16

Deadline for submission of previously unpublished papers for NCC 1977 is December 1, 1976. For further information and details of NCC Paper Guidelines, write the '77 NCC Program Chairman:

Dr. Robert R. Korfhage
Department of Computer Science
Southern Methodist University
Dallas, Texas 75275
214/692-3082

1977 CONFERENCE ON COMPUTERS IN THE UNDERGRADUATE CURRICULUM

The 8th Annual Computers in the Undergraduate Curriculum Conference will be held at Michigan State University, East Lansing, Michigan on June 19-22, 1977. A limited number of partial travel and subsistence grants may be available.

Deadline for submission of papers is January 15, 1977. For details of conference, write:

Dr. Gerald L. Engel
Virginia Institute of Marine Science
Gloucester Point, Virginia 23062

IFIP CONGRESS 77 - TORONTO, CANADA, AUGUST 8-12

The International Federation for Information Processing will hold an international congress in Toronto from August 8-12. Chairman of IFIP 77 is Prof. W. M. Turski, Institute of Mathematical Machines (MERA), Krzywickiego 34 - 02-078 Warsaw, POLAND. For information write:

Dr. Harlan D. Mills
IBM Corporation
18100 Frederick Pike
Gaithersburg, Maryland 20760

ARS EX MACHINA - VIENNA, AUSTRIA, WINTER, 1977

An international congress will be held in the winter of 1977 (precise date to be announced) in Vienna. The topic is "Correlations between Art, Nature Study and Technics." If interested, write:

Gesellschaft Bilender Kunstler Wiens
KUNSTLERHAUS
1010 Wien 1, Karlsplatz 5
AUSTRIA

EDITORIAL

TO MEASURE, TO QUANTIFY, TO KNOW?

Recently a prominent simulation expert visited our campus as a distinguished visiting professor, giving a series of guest lectures for faculty and students. I had asked him to relate the importance of computer graphics to simulation -- in addition to emphasizing the significance of simulation in problem-solving.

In order to afford objective thinking about the topics and questions raised, I have marked his topics with quotation marks, preceded by VP (for Visiting Professor). I would add that his topics were well developed in a broad, significant manner, and that I am taking them as a departure place, to briefly explore the importance (or lack of importance of interdisciplinary--not art) computer graphics.

1. VP: "You might say that computer graphics could save the world. What does this mean?"

Computer graphics enhances communication. Visual displays have been used by man throughout history to convey information. Consider the text, Limits to Growth by Meadows, Randers, and Behrens, a well-known paperback. Study the innumerable graphs in this text. Could the data and results of this simulation be displayed in a more dramatic and communicative way? Decidedly, "No." To accomplish these graphs manually would be tedious, imprecise, and unaesthetic. In essence, when computer graphing facilities are available, it is foolish (and perhaps passé) not to visualize computer processing via computer graphics. Processing of alpha-numeric data without visual displays is mere partial processing that does not display nor communicate results to the viewer or reader.

2. VP: "Many of the major and minor problems of the world can be solved by enhanced communication."

Computer graphics convey information objectively, dramatically, without emotional, subjective overtones often conveyed by numbers and words. Words too often are generalistic, colored by overuse, personal interpretations -- imprecise. Numbers convey more precise information, but they do not fully reveal relationships and results. Graphics afford a fuller, more enhanced, more understandable projection of the subject -- and communication is enhanced.

Let us look at this word "communication." If I may use computer terminology, to me, when an idea is communicated, it is throughput into the listener's (or reader's) consciousness, and processed by the receiver. Further, the material input and processed is not distorted, but conveyed in a manner that facilitates a lack of distortion, assuring maximum human comprehension.

Agreed: Enhanced communication between people can contribute to solving many of the major and minor problems of the world. In addition, enhanced communication will allow people of diverse attitudes and capacities to work together more amicably to do important tasks needed in today's complex world.

3. VP: "Simulation and visual displays are not new to man. Often simulation and visual portrayal of information allows man to cogitate about the problem, and sometimes, to solve the problem without computer processing."

Man has been formulating and visualizing symbols to communicate more precise meanings to other men since prehistory. (The excellent, edited version of James Beniger's lengthy article, "From Stylus to Light Pen: Technology and Innovation in the Development of Quantitative Graphics" reveals man's persistent efforts to portray information to other people. The techniques of conveying varied information (pictures, words, mathematics, natural and synthetic languages) offer neutral methods of communicating to other people important ideas. Simulation allows us to explore innumerable alternatives and relationships, to perceive the results of varied options, manipulations of complex variables and their interdependent interrelationships. Simulation and visualization of processes can enhance and upgrade decision-making. If we truly "cogitate" about our problems, we are in a better position to solve them.

4. GCH: "Are the problems we are simulating and processing important? Are they trivial? Are technical persons concerned with the importance or lack of importance of the material being processed by them?"

Page 24 of Limits to Growth reveals Figure 1, titled "Human Perspectives." This matrix of self, related to other selves, in time and space, is one of the most important tables I have ever seen. It graphs a person's placement in Space on the Y axis, and placement in Time on the X axis. SPACE: my family, neighborhood, race, nation...the world. TIME: next week, next few years, my lifetime, my children's lifetime...

5. GCH: "Are we wise enough, concerned enough to consider what we are processing and visualizing?"

Much processing of information is invaluable, an aid to thinking and decision-making. Yet the subject, the approach, and the programs depend upon the originator. The attitudes, concerns, and gifts of the originator determine the outcomes. This is true in computer graphics also.

The computer's most important gift to us is the capacity to cogitate, to study, to reason, to measure, and perhaps to meditate.

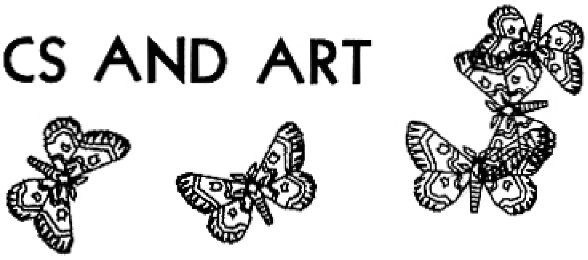
Yet when man measures, quantifies, graphs, does he "know" and understand? Where are our limits?

Computer usage and graphics visialization reveals our own limits, our own growth, but posits or places upon our individual shoulders, the predicament of mankind, and the solution to the major and minor problems of the world.

[signature] (Editor)

IT'S RENEWAL TIME - CG&A GOES INTO VOLUME TWO

COMPUTER GRAPHICS AND ART



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Learning Through Graphics
by Dr. Al Bork, University of California, Irvine, California
A ten-year forecast for computers, education, and graphics by a leading authority.

Art of the Technical World
by Dr. Herbert Franke, Munich, Germany
Computer art as the bridge between the two realms of art and leisure.

Expanding the Graphics Compatability System to Three Dimensions
by Richard F. Puk, Purdue University, Lafayette, Indiana
Design considerations for a user-oriented 3-D graphics system.

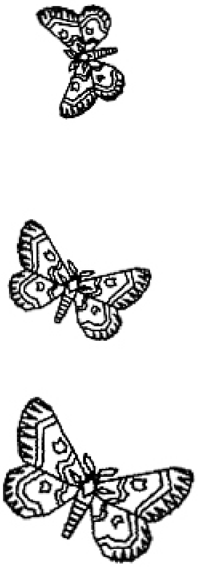
A Personal Philosophy of Ideas, New Hardware, and the Results
by Duane Palyka, University of Utah, Salt Lake City, Utah
The frame-buffer from Evans and Sutherland allows the artist to treat the computer as a paint and brush medium.

How to Build Fuzzy Visual Symbols
by Alex Makarovitsch, Honeywell Bull, Paris, France
A new approach to computer art and graphics by a computer scientist.

The State of the Art of Computer Art
by Grace C. Hertlein, Editor
Comparisons of early computer art and today's newer art. What is art? What is art in computer art?

Inexpensive Graphics from a Storage Cathode Ray Tube
by Charles J. Fritchie and Robert H. Morriss, Tulane University, New Orleans, Louisiana
Illustrations and photographic techniques used to achieve graphics from a storage tube CRT.

An Investigation of Criteria for Evaluating Computer Art
by Thomas E. Linehan, Ohio State University, Columbus, Ohio
The new aesthetic of computer art requires a departure from the previous, formalist-traditionalist doctrines for evaluating art.



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- Cartography Systems
- Computer-Aided Design
- Computer Assisted and Managed Instruction Utilizing Computer Graphics
- Computer Graphics in Physics, Chemistry, Mathematics, etc.
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- Display Systems and Graphics
- Fine Art and Media Explorations
- Graphics in Business
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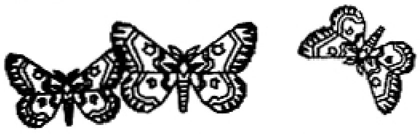

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( ) Additional Comments (attach another paper if needed):____________________

MATHEMATICS IN ART AND COMPUTER GRAPHICS

by Dr. Jean H. Bevis
Department of Mathematics
Georgia State University
Atlanta, Georgia 30303

"If one examines graphics work in general, you find systematic collections of lines. It is surprising how many of these are variations or combinations of the two methods discussed. Could this lead to a new mathematical theory?...A study of techniques for specifying a basic system of lines and the relationships between such techniques could lead to a mathematical theory of texture."

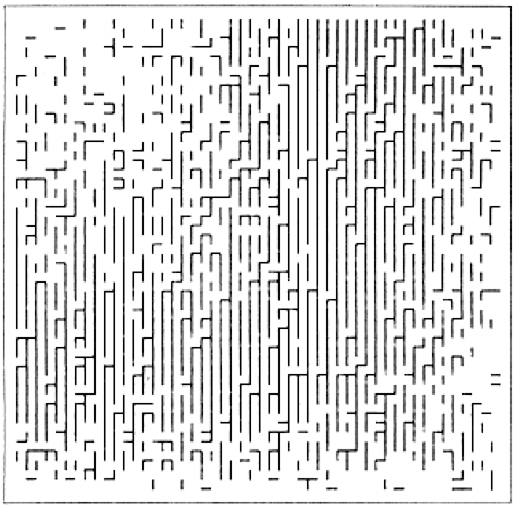
MATHEMATICS EXPERIENCE AND ART

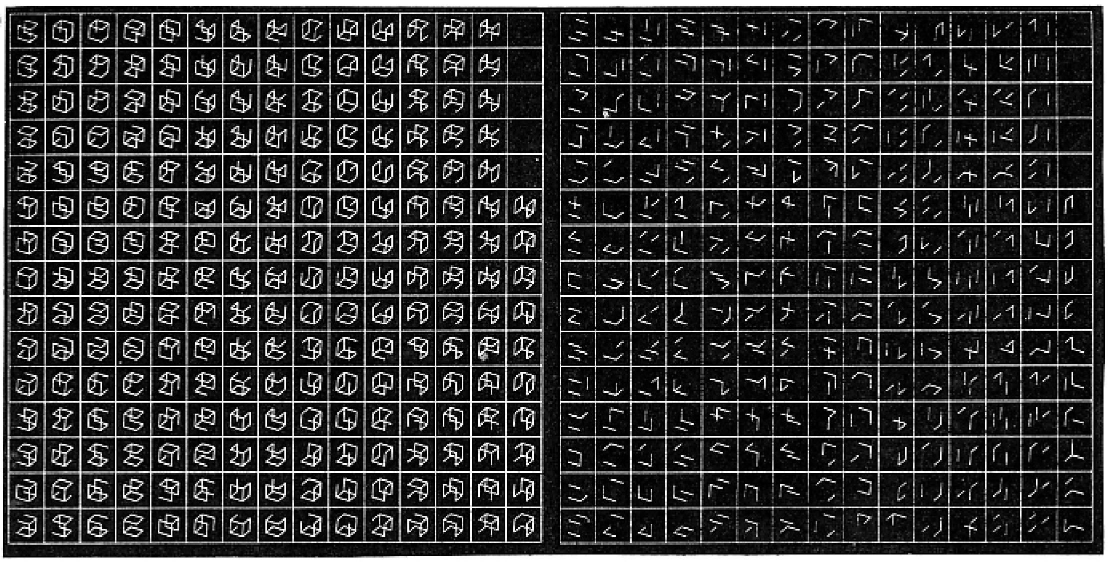
Mathematical topics can be important to an artist doing computer graphics, but is it really necessary for the artist to be aware of these topics In the past, computer graphics could only be done by people with programming ability. Much of the work reflected this mathematical experience. Recently software packages have become available to make this medium available to those with no mathematical or programming experience.

LEVELS OF MATHEMATICS IN COMPUTER ART

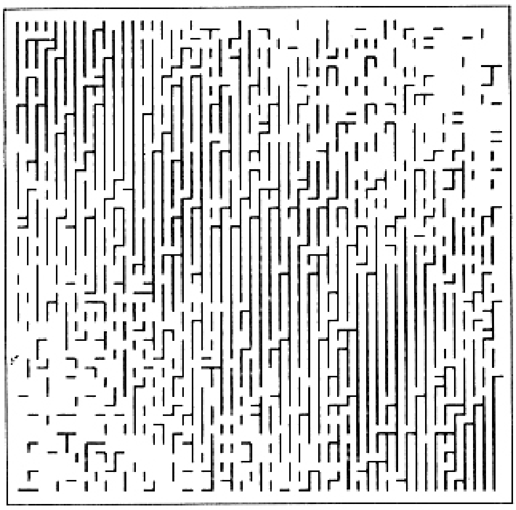
Mathematics relates to computer art on several levels. The highest level includes visual representations of mathematical concepts. Here there is a danger of letting mathematics overshadow artistic considerations, but there are many fine examples. Aldo Giorgini achieves great feeling in his drawings (1, page 9) which are based on the theory of hydro-mechanics. Frieder Nake in "Matrix Multiplication" (2, page 26) uses color to represent matrix multiplication. Combinatorics is the theory behind "The Cubic Limit Series" by Manfred Mohr (see illustration).

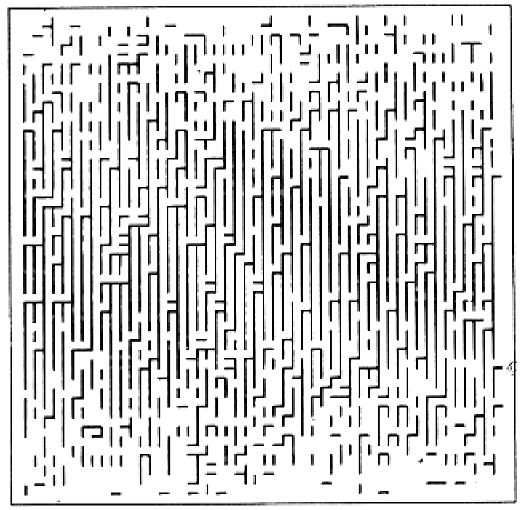
BELOW (and TOP, NEXT PAGE) - "Random Walk Through Raster," 1966, examples of mathematics in art.





Generative Drawings from the Cubic Limit Series, Manfred Mohr
(This Series was shown in Paris, May-June 1975.)





ABOVE: Further examples by F. Nake, variations.

Although a computer was not used, M. C. Escher's drawings involving Moebius strips are beautiful examples of this relationship between mathematics and art.

MATHEMATICS AND GRAPHICS

At another level is the artist who writes his or her own computer programs to execute visual ideas. This artist should have a basic knowledge of analytic geometry.

Mathematics departments of colleges and universities offer freshman coursework which is helpful. Here there is an exciting possibility of using art to teach mathematics. That is, to introduce and motivate mathematical concepts as ways of solving visual problems.

Such a course is now being developed at Georgia State University.

BEGINNING EXAMPLES

No mathematics is required of an artist who is supplied with an appropriate software package. This is a tool that can translate the user's ideas into a visual image. Examples of such tools include EXPLOR developed by Ken Knowlton at Bell Laboratories; SPLAT developed by John Skelton at the University of Denver; and ARPE which I developed at Georgia State University.

With these programs, the user's only concern is with design, not mathematics or programming. To be successful such programs must allow the user to develop personal styles or techniques, rather than to produce variations of the programmer's visual concepts. This richness may be accomplished by making it possible to use the programs in ways not intended (an example is given to clarify this concept).

These programs allow the user to create a drawing by assembling "basic elements or figures", controlling location, size, orientation, and density. For drawings to be done on a pen plotter, basic figures are simply "systematic collections of lines".

Basic figures are very important to a graphics software package. Without them the user might as well proceed to the above level and write his own program.

BASIC FIGURES

The most fundamental type of basic figure could consist of two arrays X(K), Y(K) K = 1, 2,..., N which would specify the coordinates of points along the outline of some design such as a sea shell or butterfly. These arrays could be introduced by a light pen or figured out on a graph paper and entered as data values.

The software package is then used to manipulate the design.

Klaus Thomas (2, pages 120-121) uses a different type of basic figure. Here a number of points, the corners of the drawing, are specified. Then the pen moves around the perimeter from corner to corner. On successive circuits the pen moves only a fraction (say 95%) of the way to the next corner and the corners are replaced by new points.

EXAMPLES FROM THE ARPE SYSTEM

ARPE uses two types of basic elements, illustrated in Figures 1 and 2. Both of these are based on the two curves shown in Figure 3.

To produce Figure 1 a number of points (determined by the density) are selected along each curve and then points on one curve are connected by lines to corresponding points on the other curve. If the coordinates of points along the curves are given in the arrays X(K), Y(K), V(K) with K = 1, 2,...,N, then the figure may be produced by the code:

```
FOR K = 1 TO N
MOVE TO (X(K), Y(K))
DRAW TO (U(K), V(K))
NEXT K
```

Figure 2 is produced by an averaging process, drawing curves intermediate between the two given curves. If M curves are to be drawn, the figure is given by the code:

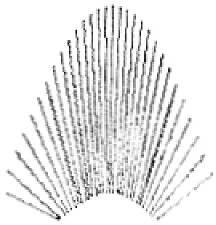


Figure 1.

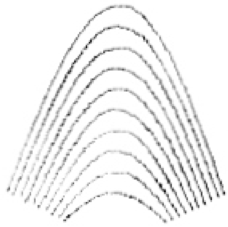


Figure 2.

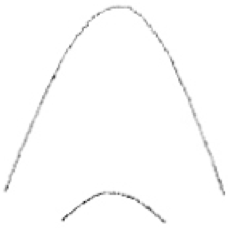


Figure 3.

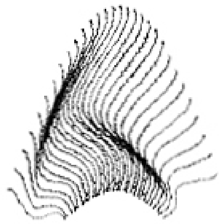


Figure 4.

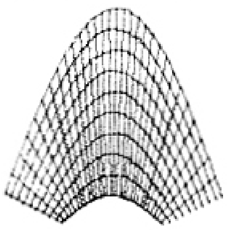


Figure 5.

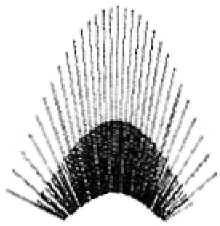


Figure 6.

```
FOR I = 1 TO M
A = ((M-I)* X(1) + (I-1)*U(1))/(M-1)
B = ((M-I)* Y(1) + (I-1)* V(1))/(M-1)
MOVE TO (A,B)
FOR K = 2 TO N
A = ((M-I)* X(K) + (I-1)* U(K))/(M-1)
B = ((M-I)* Y(K) + (I-1)* V(K))/(M-1)
DRAW TO (A,B)
NEXT K
NEXT I
```

Thus the intermediate curves are weighted averages of the two given curves. "Running Cola is Africa" done by the Computer Technique Group of Japan (2, page 34) is a good example of this method.

Figure 4 shows a variation of Figure 1 where the connecting lines have been replaced by connecting curves. To do this the arrays representing the connecting curve must be transformed so that the the end points of the curve match the points to be connected. The transformation accomplishing this feat may be adapted to "connecting" closed curves that really don't connect. Although the original intention or concept of the program was connecting curves, provision was made for other use.

This is an example of planning for non-intended use as mentioned above.

Figures 5 and 6 are composed of two basic figures each. It becomes apparent that designing basic figures deals with texture.

Further variations of the two basic figures are planned using the technique of modulation developed by Charles Williams (Georgia State University). By modulation the lines and curves of basic figures may be replaced by dotted, wavy, jagged, humped, and looped curves, or even changed to sequences of closed figures.

SUMMARY

If one examines graphics work in general, you find systematic collections of lines. It is surprising how many of these are variations or combinations of the two methods above. Could this lead to a new mathematical theory?

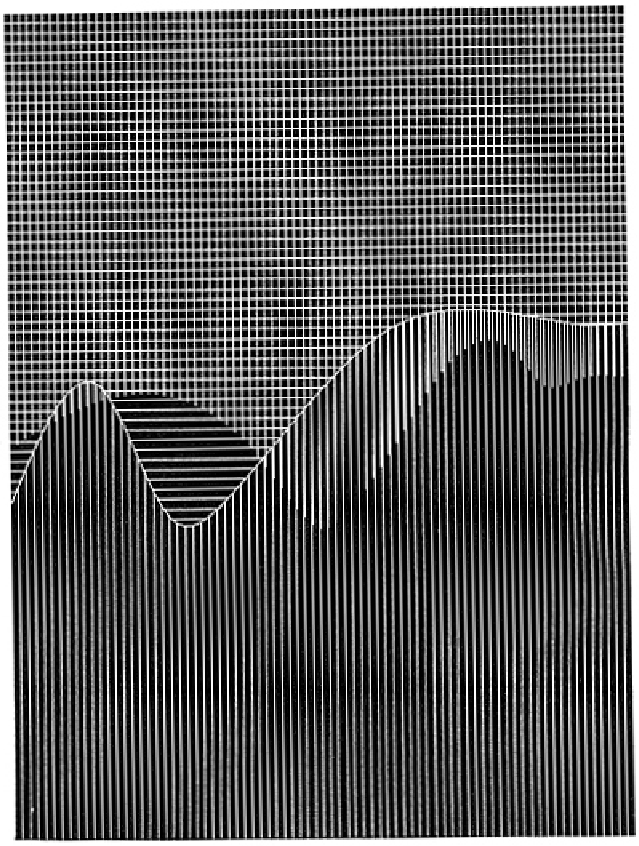
For example, hundreds of years ago man was fascinated by problems concerning factoring numbers and polynomials. This led to the mathematical theory of rings. A study of techniques for specifying a basic system of lines and of the relationships between such techniques could lead to a mathematical theory of texture.

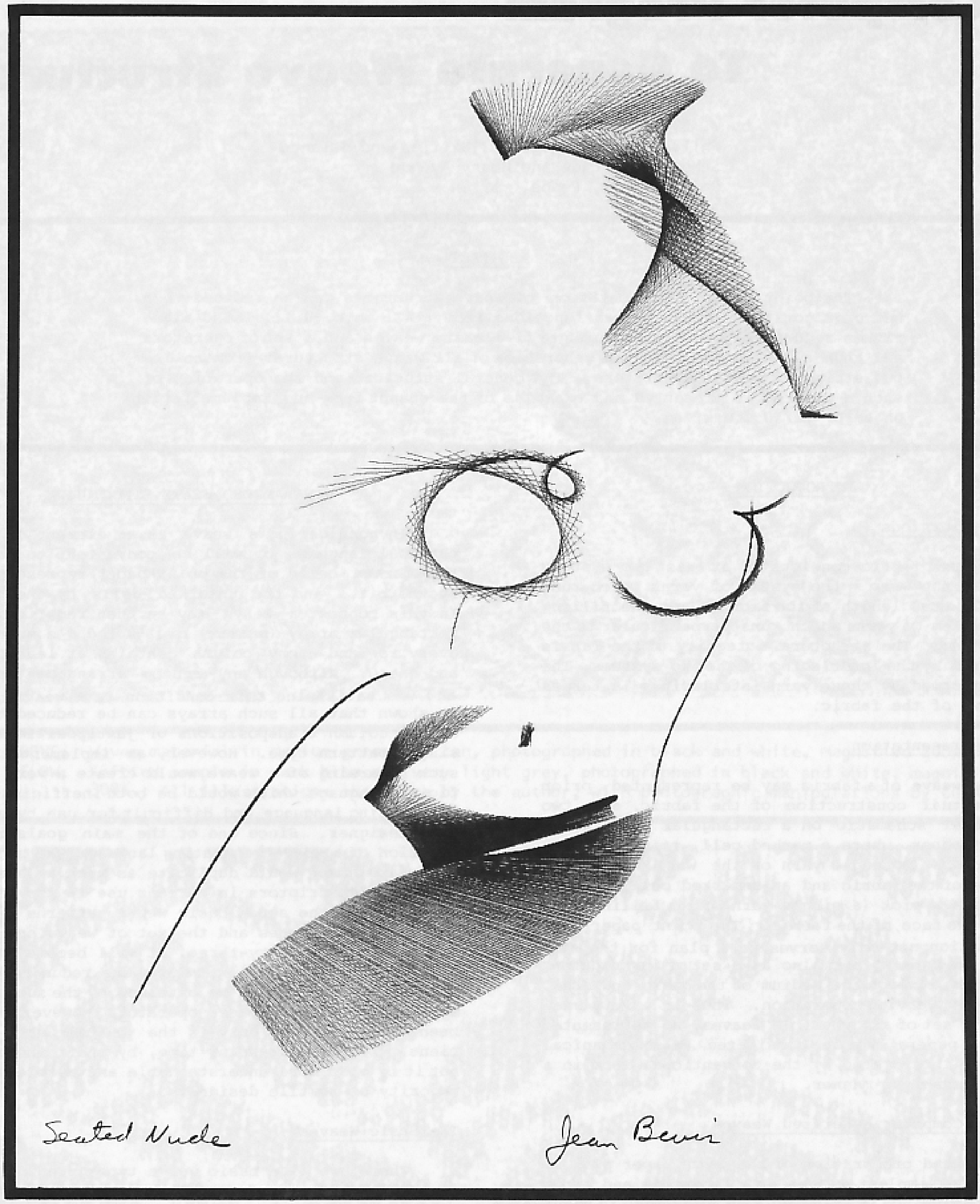
REFERENCES

1. Leavitt, Ruth, Artist and Computer, Harmony Books, New York, 1976.

2. Franke, Herbert W., Computer Graphics and Computer Art, Phaidon, London, 1971.

BELOW: Detail of P145 - "Phase Pattern" by Manfred Mohr, 50 X 50 cm.





ABOVE: "Seated Nude" by Jean Bevis makes use of the varied possibilities for textures and variations of Figures 1 - 6.

This is perhaps one of the most subtle (if not the most delicate and subtle) nude accomplished thus far with the aid of the computer. The lyrical lines poetically suggest the form, yet positive and negative areas are poised in a serene balance. Jean Bevis is acutely aware of the void area, does not cram his forms with multitudinous interference patterns, simply because the computer affords this linear possibility. He has the sensitivity and graciousness to "leave out" -- to suggest and understate the idea.

The work is an excellent example of the author's search for a unity of mathematics, science, and art. Ironically, it is a variation on a theme of mathemtical functions! Let those overly enamoured of insensitive and non-inventive uses of mathematical formulas study the work of this sensitive mathematician.

I predict that this work will become a favorite (and enduring) computer classic. (GCH)

A Computer Program To Generate Weave Structures

by W. G. Wolfgang
Philadelphia College of Textiles and Science
Schoolhouse Lane and Henry Avenue
Philadelphia, Penna. 19144

ABSTRACT

The point paper representation of weave structures can be reduced to a set of algorithms which act as functions from $I \times I$ into $\{0,1\}$. These algorithms reduce all weave structures to five basic weaves and a set of operators and thus allow for the computer generation of all weave structures from an input string of weave descriptors. The general structure and the operation of such a program is presented and examples of the output from an implementation on a PDP-11/20 are given.

INTRODUCTION

Basic Definitions

A woven fabric consists of at least two systems of yarns; the *warp* - the system of yarns which runs parallel to the length of the fabric, and the *filling* - the system of yarns which runs perpendicular to the warp system. The structural integrity of the fabric is assured by the *interlacing* of the two systems. The pattern formed by these yarn interlacings is termed the *weave* of the fabric.

Weave Representation

The weave of a fabric may be represented, prior to the actual construction of the fabric, as a two dimensional schematic on a rectangular grid, known as *point paper*, where a marked cell, *raiser*, represents an *end* (a single yarn of the warp system) on the face of the fabric and an unmarked cell, *sinker*, represents a *pick* (a single yarn of the filling system) on the face of the fabric. The point paper representation not only serves as a plan for the structure of the fabric, but also as a set of instructions to the loom, through the medium of the *chain* and *draw*, during the weaving operation. Thus in a very real sense the set of all possible weaves, as represented on point paper, may be considered as a mechanical language, interpreted by the conventional loom in a purely mechanical manner.

Need for Computer Generated Weaves

The hand preparation of the point paper plan of all but the simplest weaves is a laborious and error prone task. Since it is capable of reduction to a set of relatively simple algorithms it is more properly in the domain of a computer activity than in human activity. With the imminent possibility of wider use of computer controlled looms (computer controlled knitting machines are already accomplished facts) it is the opinion of the author that a more versatile instruction set should be available for such a loom or knitting machine. It is the purpose of this paper to present such an instruction set, in the form of a string language of weave descriptors and a program which will interpret these strings and cause a computer to execute the proper algorithm and generate the point paper representation of the desired weave. By a simple change in the output routines, the program could also be used for the direct control of a loom or knitting machine.

GENERALIZED WEAVE STRUCTURES

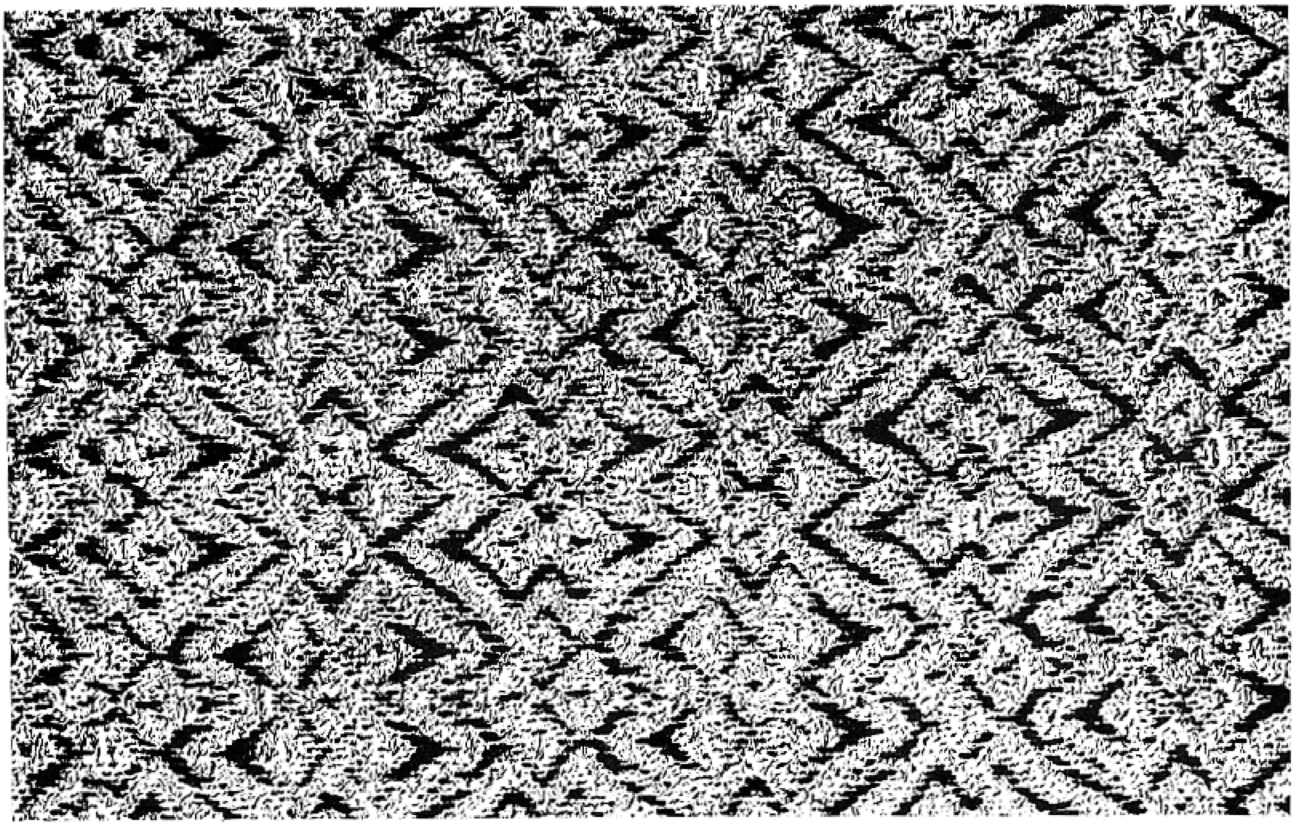
In considering a weave as an element of a mechanical language it will be convenient to replace the marked cells of the point paper representation by the bit 1 and the unmarked cells by the bit 0. In this context a weave may be then redefined as a rectangular array (matrix) of 1's and 0's such that every row and every column contains at least one 1 and one 0. Although any random arrangement of 1's and 0's satisfying this condition is a weave, it can be shown that all such arrays can be reduced to row and/or column transpositions or juxtapositions of a single pattern type. However, an implementation of such a parsing of a weave would create a very artificial language which would be both inefficient as a programming language and difficult for use by a textile designer. Since one of the main goals in the creation of a weave generating language was to create a syntax which would duplicate as much as possible the weave descriptors in current use in the textile design field, the set of basic weave patterns was expanded to five types and the set of weave operators was expanded to twenty-three. It will become obvious that many of the weave operators are redundant, that is, their operation can be obtained by the successive application of more basic operators, however, it has been found that not only is the program more efficient, in terms of running time, by their inclusion, but it is also more understandable and usable by the majority of textile designers.

The Basic Weaves

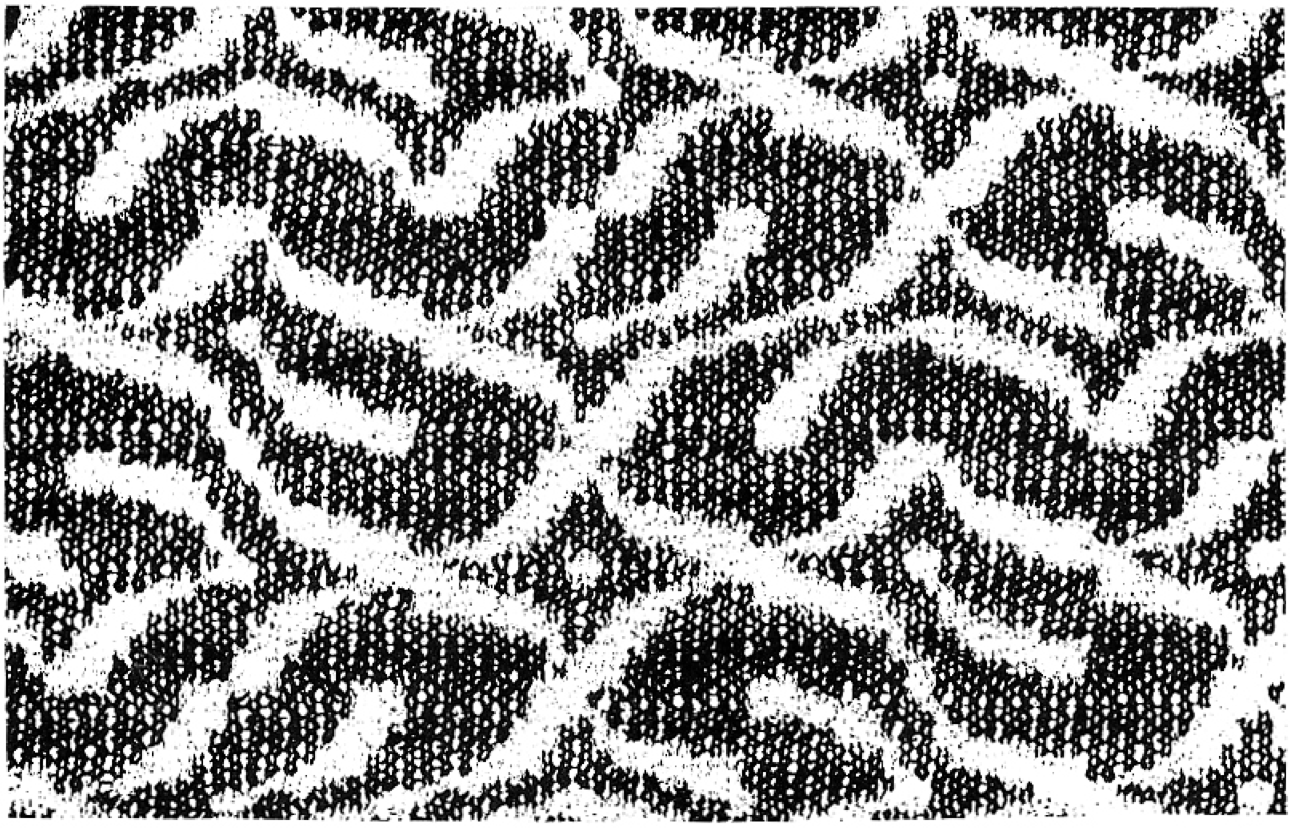
There are five basic weave types preprogrammed in the language; *basket weave* - which includes the plain weave of the textile designer as a special case, *warp rib weave, filling rib weave, extended block weave* - a generalization of the basket weave in which the diagonal is formed of rectangles rather than the usual squares, and *twill weave* - a generalization of the twill concept of the textile designer which will also generate the satins and certain granite weaves as special cases.

BAsket weave - BW$(m_1, m_2, \ldots, m_i)$ This will form a $m_1, m_2, \ldots, m_i$ basket weave. That is a weave which has a diagonal pattern of square blocks of raisers which are m_1 by $m_1, \ldots, m_i$ by m_i.

Rib Weave - WR$n(m_1, m_2, \ldots, m_i)$ This will form a conventional $m_1, m_2, \ldots, m_i$ warp rib if n is either 1 or left blank. Otherwise a corresponding warp rib in



ABOVE: Woven material in medium green and tan, photographed in black and white, magnified 200%.
BELOW: Knitted sample in dark blue and very light grey, photographed in black and white, magnified 300%. All illustrations shown are by the author, with photographic manipulations by CG&A.



which n picks weave as one.

Filling Rib - FRn($m_1, m_2, \ldots, m_i$) This will form a conventional filling rib if n is 1 or left blank, otherwise it will form a corresponding filling rib in which n ends weave as one.

Extended Block - EB($m_1, n_1, m_2, n_2, \ldots, m_i, n_i$) The weave is analogous to the basket weave except that the diagonal is formed of rectangles m_1 by $n_1, \ldots, m_i$ by n_i rather than squares as in the basket.

Twill Weave - TW($m_1, n_1, m_2, n_2, \ldots, m_i, n_i, s, k$) In order that the array generated by this algorithm be a weave the parameter, k, must satisfy certain requirements.

Let $S = \sum_{j=1}^{i} (m_j+n_j)$, $N = \max(m_j, n_j)$, $M = \min(N, S-N)$

then k must satisfy one of the following:

a. $|k|$ and S must be relatively prime, or

b. $|k| \leq M$, or

c. $|S-k| \leq M$, or

d. $gcd(|k|, S) \leq M$, where gcd means greatest common divisor.

If s>0 then columns are operated on in the generation of the array by the twill weave algorithm. If s<0 then rows are operated on. The array is generated as follows. If $|s| = 1$ then the first column (row) of the array consists of m_1 successive 1's followed by n_1 successive 0's followed by m_2 successive 1's followed by n_2 successive 0's etc, beginning at the bottom (left) and proceeding upward (to the right). The elements of all succeeding columns (rows) are generated by the following rule. The j'th element of the i'th column (row) is the ℓ'th element of the 1'st column (row) where $j = (\ell+(i-1)k) \bmod S$. For $|s| \neq 1$ the first row (column) of the array generated will be the $|s|$'th row (column) of the array generated for $|s| = 1$. This algorithm generalizes the concept of the twill weave of the textile designer as it includes weaves which are not ordinarily considered as twills. It also includes the conventional satins when the form is TW(n,1,-1,k) for a n+1 harness, warp face satin with a counter of k or TW(1,n,-1,k) for a n+1 harness filling face satin with counter k provided in both cases that k and n+1 are relatively prime.

The Weave Operators

Any weave can be modified or combined with any other weave to form a new weave by the application of one or more of the following operators. In the sequel W, W_1 and W_2 will represent any weave, that is one of the basic weaves or a weave already generated by the application of one or more of the weave operators. Weaves are periodic both vertically and horizontally, thus p_i and e_i will represent the height and width, respectively, of a single period of the corresponding weave, (i.e. the number of rows and the number of columns in a single period of the weave).

Horizontal Concatination - HC(W_1, W_2) A weave which consists of the weave W_1 on the left with the weave W_2 placed to its immediate right. If the two weaves do not repeat on the same number of rows then both will be repeated vertically a sufficient number of times to give arrays having a number of rows equal to $lcm(p\ ,p\ )$, where lcm stands for the least common multiple.

Vertical Concatination - VC(W_1, W_2) A weave which consists of the weave W_1 placed immediately above the weave W_2. If the two weaves do not repeat on the same number of columns then each will be repeated horizontally a sufficient number of times to give arrays having a number of columns equal to $lcm(e_1, e_2)$.

ANd - AN(W_1, W_2) An array which has 1's in those locations where both W_1 and W_2 have 1's and 0's elsewhere.

OR - OR(W_1, W_2) An array which has 1's in those locations where either W_1 or W_2 has 1's and 0's in all other locations.

In both the AND and OR operators the weaves will be repeated, if necessary, vertically and horizontally to give arrays having $lcm(p_1, p_2)$ rows and $lcm(e_1, e_2)$ columns. In general the AND and OR operators will not give weaves when applied to arbitrary weaves, however, a weave will always result when they are applied to twills having the same value of K and for which the values of s have the same sign. These operators are most useful in the process or replacing the raisers and/or sinkers of a given weave with another weave or weaves.

COlate - CO(W_1, W_2) An array in which the elements at the intersections of the odd numbered rows and odd numbered columns are the elements of the weave W_1 and the elements at the intersection of the even numbered rows and columns are the elements of W_2. All other elements are 0's. The weaves will be repeated, if necessary, as in the AND and OR operators.

```
PCT&S WEAVE LANGUAGE     28-SEP-76  22:06:59

BR[8,5,3;5,3:TW(4,4,1,1)]

     -XXXX---XXX--XX-X----XXX---XX--X
     --XXX---XXXX-X--XX---XXX----X-XX
     ---XX--X-XXXX---XXX--XX-X----XXX
     XXX--XX-X----XXX---XX--X-XXXX---
     XX---XXX----X-XX--XXX---XXXX-X--
     X----XXX---XX--X-XXXX---XXX--XX-
     ----X-XX--XXX---XXXX-X--XX---XXX
     ---XX--X-XXXX---XXX--XX-X----XXX
     XXX--XX-X----XXX---XX--X-XXXX---
     XXXX-X--XX---XXX----X-XX--XXX---
     -XXXX---XXX--XX-X----XXX---XX--X
     X----XXX---XX--X-XXXX---XXX--XX-
     ----X-XX--XXX---XXXX-X--XX---XXX
     ---XX--X-XXXX---XXX--XX-X----XXX
     --XXX---XXXX-X--XX---XXX----X-XX
```

PCT&S WEAVE LANGUAGE 28-SEP-76 22:03:45

```
BR[8,5,3;5,3:TW(4,4,1,3)]

-X-XX--X-XX-X-X-X-X--XX-X--X-X-X
-X--X-XX--X-X-X-X-XX-X--XX-X-X-X
-XX-X-X-X-X--XX-X--X-X-X-X-XX--X
X--X-X-X-X-XX--X-XX-X-X-X-X--XX-
X-XX-X--XX-X-X-X-X--X-XX--X-X-X-
X-X--XX-X--X-X-X-X-XX--X-XX-X-X-
--X-X-X-X-XX-X--XX-X-X-X-X--X-XX
-XX-X-X-X-X--XX-X--X-X-X-X-XX--X
X--X-X-X-X-XX--X-XX-X-X-X-X--XX-
XX-X-X-X-X--X-XX--X-X-X-X-XX-X--
-X-XX--X-XX-X-X-X-X--XX-X--X-X-X
X-X--XX-X--X-X-X-X-XX--X-XX-X-X-
--X-X-X-X-XX-X--XX-X-X-X-X--X-XX
-XX-X-X-X-X--XX-X--X-X-X-X-XX--X
-X--X-XX--X-X-X-X-XX-X--XX-X-X-X
-X-XX--X-XX-X-X-X-X--XX-X--X-X-X
```

<u>Double Cloth</u> - DC(W_1,W_2) The array formed is the same as in the COLATE operator except that the elements at the intersection of the even numbered rows and odd numbered columns are 1's.

<u>Colate Ends</u> - CE(W_1,W_2) An array in which the odd numbered columns are the columns of W_1 while the even numbered columns are the columns of W_2. The weaves will be repeated, if necessary, as in HORIZONTAL CONCATINATION.

<u>Colate Picks</u> - CP(W_1,W_2) An array in which the odd numbered rows are the rows of W_1 while the even numbered rows are the rows of W_2. The weaves will be repeated, if necessary, as in VERTICAL CONCATINATION.

<u>NoT</u> - NT(W) A weave which has 1's where ever W has 0's and 0's where ever W has 1's.

<u>TransPose</u> - TP(W) A weave whose rows are the columns of W and whose columns are the rows of W.

<u>InVert</u> - IV(W) A weave whose i'th row is the (p-i+1) th row of W.

<u>ReFlect</u> - RF(W) A weave whose i'th column is the (e-i+1)'th column of W.

<u>ROtate</u> - RO(n:W) If n = 1 the resulting weave is W rotated counterclockwise through 90°, if n = 2 the resulting weave is W rotated through 180° and if n=3 the resulting weave is W rotated through 270° counterclockwise (90° clockwise). No other values are permissable for n.

<u>RePeat</u> - RP(m,n:W) A weave which consists of W repeated m times horizontally and n times vertically.

<u>EXpand</u> - EX(m,n:W) A weave which consists of every column of W repeated m times in succession (i.e. m column 1's followed by m column 2's etc.) and each row of the resulting array repeated n times.

<u>Column Transposition</u> - CT(c_1,...,c_n:W) A weave whose i'th column is the c_i'th column of W.

<u>Row Transposition</u> - RT(r_1,...,r_n:W) A weave whose i'th row is the r_i'th row os W.

In addition there are three operators which generate, in the program, the proper row and/or column transpositions to form the *pointed*, *broken* and *skip* twill structures when applied to this type of weave. Their syntax is as follows:

<u>Point</u> - PT(h,e_1,...,e_m;p_1,...,p_n:W)

<u>Break</u> - BR[h,e_1,...,e_m;p_1,...,p_n:W]

<u>Skip</u> - SK[h,e_1,...,e_m;p_1,...,p_n:W]

<u>A Recursive Definition</u>

Using the weaves and operators defined above, a weave can be defined in its most general form by:

<BW> =:: BA(m_1,...,m_i)|FR*n*(m_1,...,m_i)|WR*n*(m_1,...,m_i)
|EB(m_1,n_1,...,m_i,n_i)|TW(m_1,n_1,...,m_i,n_i,s,k)

<DO> =:: HC|VC|AN|OR|CO|CE|CP

<SO> =:: NT|TP|IV|RF

<PO> =:: RO(n:|RP(m,n:|EX(m,n:|CT(c_1,...,c_n:|RT(r_1,...,r_n:

< *W* > =:: *<BW>*|*<DO>*(*<W>*,*<W>*)|*<SO>*(*<W>*)|*<PO><W>*)

<u>Interpretation</u>

<u>As a Constructional Algorithm</u> - The algorithms given above for the basic weaves and the weave operators are constructional in nature, that is to evaluate a string such as HC(BA(3,2),AN(TW(5,3,1,1),BA(1,1))) one would be required to first work out all the basic weaves and then carry out the given operations. Although such an interpretation could be carried out on a digital computer the amount of temporary storage required would be prohibitive if complex weaves were contenplated.

<u>As a Function</u> - A more efficient approach, and the one used in the program to be described, would be to consider the weave as a function from *I* x *I* into the set {0,1}. That is given a cell location (i,j) then the algorithm W should decide whether to place a 1 or a 0. If it is assumed that the weave array is initially filled with 0's then the following algorithms will decide which of these will be replaced with 1's.

Let $X_r = \sum_{\ell=0}^{r} x_\ell$ where $X_0 = 0$, $x_0 = 0$, X = M or N and x = m or n.

BA(m_1,...,m_r)(i,j)=1 if there exists $k \geq 0$ and $n \geq 0$ such that $M_{2k} \leq i < M_{2k+1}$ and $M_{2n} \leq j < M_{2n+1}$ or $M_{2k+1} \leq i < M_{2k+2}$ and $M_{2n+1} \leq j < M_{2n+2}$

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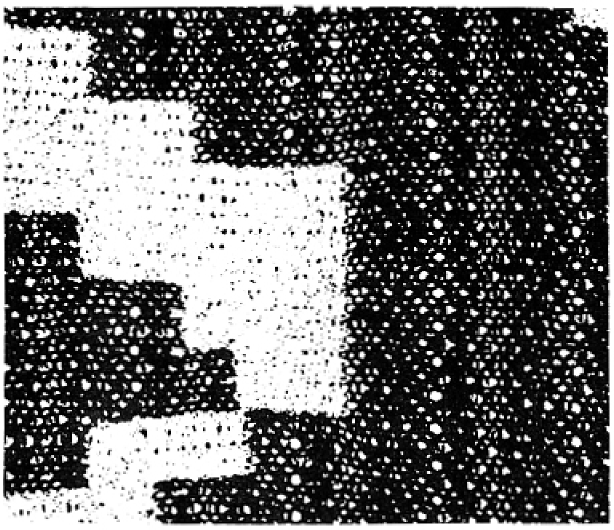


$WRn(m_1,\ldots,m_r)(i,j) = 1$ if there exists $k \geq 0$ such that $M_{2k} \leq i < M_{2k+1}$ and $0 \leq j < n$ or $M_{2k+1} \leq i < M_{2k+2}$ and $n \leq j < 2n$

$FRn(m_1,\ldots,m_r)(i,j) = 1$ if there exists $n \geq 0$ such that $0 \leq i < n$ and $M_{2k} \leq j < M_{2k+1}$ or $n \leq i < 2n$ and $M_{2k+1} \leq j < M_{2k+2}$

$EB(m_1,n_1,\ldots,m_r,n_r)(i,j) = 1$ if there exists $k \geq 0$ and $n \geq 0$ such that
$M_{2k} \leq i < M_{2k+1}$ and $N_{2k} \leq j < N_{2k+1}$
$M_{2k+1} \leq i < M_{2k+2}$ and $N_{2k+1} \leq j < N_{2k+2}$ or

Let $S = \sum_{\ell=0}^{r} (m_\ell+n_\ell)$, $M_k = \sum_{\ell=0}^{k} (m_\ell+n_\ell)$ and $M_0 = 0$

$TW(m_1,n_1,\ldots,m_r,n_r,s,k)(i.j) = 1$

a. If $s > 0$ and there exists a p such that
$(|s|+k(i-1)+M_p) \bmod S \leq j < (|s|+k(i-1)+M_p+m_p) \bmod S$
or
b. If $s < 0$ and there exists an e such that
$(|s|+k(j-1)+M_e) \bmod S \leq i < (|s|+k(j-1)+M_e+m_e) \bmod S$

$HC(W_1,W_2)(i,j) = \begin{cases} W_1(i,j^*) & 0 \leq i < e_1-1,\ j^*=j \bmod p_1 \\ W_2(i,j^*) & e_1 \leq i < e_1+e_2-1,\ j^*=j \bmod p_2 \end{cases}$

$VC(W_1,W_2)(i,j) = \begin{cases} W_1(i^*,j) & i^*=i \bmod e_1,\ 0 \leq j < p_1-1 \\ W_2(i^*,j) & i^*=i \bmod e_2,\ p_1 \leq j < p_1+p_2-1 \end{cases}$

$AN(W_1,W_2)(i,j) = 1$ if $W_1(i_1,j_1)=1$ and $W_2(i_2,j_2)=i$
$i_i = i \bmod e_i,\ j_i = j \bmod p_i$

$OR(W_1,W_2)(i,j) = 1$ if $W_1(i_1,j_1)=1$ or $W_2(i_2,j_2)=1$

$CO(W_1,W_2)(i,j) = \begin{cases} W_1(i^*,j^*), & i=2i^*-1,\ j=2j^*-1 \\ W_2(i^*,j^*), & i = 2i^*,\ j=2j^* \end{cases}$

$DC(W_1,W_2)(i,j) = \begin{cases} 1 \text{ if } i = 2i^*-1,\ j = 2j^* \\ W_1(i^*,j^*), & i = 2i^*-1,\ j=2j^*-1 \\ W_2(i^*,j^*), & i = 2i^*,\ j = 2j^* \end{cases}$

$CE(W_1,W_2)(i,j) = \begin{cases} W_1(i^*,j), & i=2i^*-1 \\ W_2(i^*,j), & i = 2i^* \end{cases}$

$CP(W_1,W_2)(i,j) = \begin{cases} W_1(i,j^*), & j = 2j^*-1 \\ W_2(i,j^*), & j = 2j^* \end{cases}$

$NT(W)(i,j) = 1$ if $W(i,j) = 0$.

$TP(W)(i,j) = W(j,i)$

$IV(W)(i,j) = W(i,p-j+1)$

$RF(W)(i.j) = W(e-i+1,j)$

$RO(1:W)(i,j) = W(p-j+1,i)$

$RO(2:W)(i,j) = W(e-i+1,p-j+1)$

$RO(3:W)(i,j) = W(j,e-i+1)$

$RP(m,n:W)(i,j) = W(i^*,j^*)$ $i^*=i \bmod e,\ j^*=j \bmod p$

$EX(m,n:W)(i,j) = W(i^*,j^*)$ $i^* = [i/m],\ j^* = [j/n]$

$CT(c_1,\ldots,c_n:W)(i,j) = W(c_i,j)$

$RT(r_1,\ldots,r_n:W)(i,j) = W(i,r_j)$

Weave Dimensions - Since the above algorithms require knowledge of the dimensions of a single period of the weave, an algorithm is also necessary to produce the associated pair of numbers from the weave descriptor. These algorithms are as follows :

$BA(m_1,\ldots,m_r) \rightarrow (\sum_{i=1}^{r} m_i, \sum_{i=1}^{r} m_i)$

$FRn(m_1,\ldots,m_r) \rightarrow (\sum_{i=1}^{r} m_i, 2n)$

$WRn(m_1,\ldots,m_r) \rightarrow (2n, \sum_{i=1}^{r} m_i)$

$EB(m_1,n_1,\ldots,m_r,n_r) \rightarrow (\sum_{i=1}^{r} m_i, \sum_{i=1}^{r} n_i)$

$TW(m_1,n_1,\ldots,m_r,n_r,s,k) \rightarrow (S \bmod(gcd(S,k)), S)$ s 0
$TW(m_1,n_1,\ldots,m_r,n_r,s,k) \rightarrow (S, S \bmod(gcd(S,k)))$ s 0

$HC(W_1,W_2), CE(W_1,W_2) \rightarrow (e_1+e_2, lcm(p_1,p_2))$

$VC(W_1,W_2), CP(W_1,W_2) \rightarrow (lcm(e_1,e_2), p_1+p_2)$

$AN(W_1,W_2), OR(W_1,W_2) \rightarrow (lcm(e_1,e_2), lcm(p_1,p_2))$

$CO(W_1,W_2), DC(W_1,W_2) \rightarrow (2(lcm(e_1,e_2)), 2(lcm(p_1,p_2)))$

$NT(W), RF(W), IV(W), RO(2:W) \rightarrow (e,p)$

$TP(W), RO(1:W), RO(3:W) \rightarrow (p,e)$

$RP(m,n:W), EX(m,n:W) \rightarrow (me,np)$

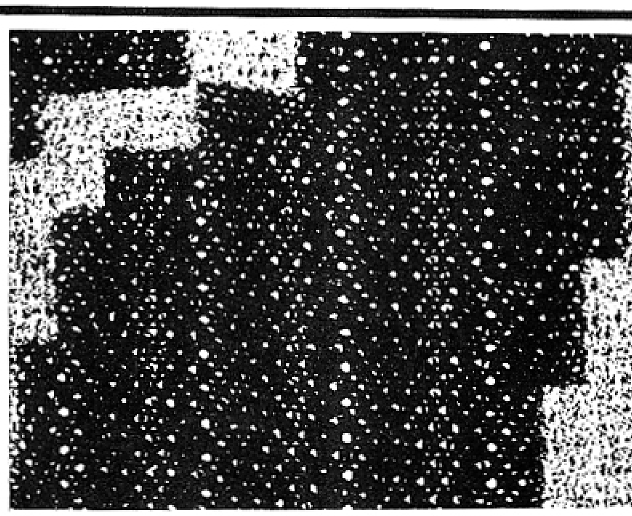
$CT(c_1,\ldots,c_n:W) \rightarrow (n,p)$

$RT(r_1,\ldots,r_n:W) \rightarrow (e,n)$

THE WEAVE PROGRAM

General Structure

The weave language program consists of three parts; an interpreter, *Decode*, for the weave descriptor strings, an operating program, *Perform*, and a set of subroutines which implement either the dimension algorithms or the functional algorithms of the basic weaves or weave operators. The heart of the program is a linked list of addresses of the weave algorithm subroutines called *Current Weave*, with a location pointer, *Curwe*. In addition there is an associated list of numerical parameters, *Operational Parameters*, with location pointer, *Oparm*,



and three push downs; *Current End*, with location pointer, *Curen, Current Pick*, with location pointer *Curpi*, and *Next Weave*, with pointer, *Nxtwe*. Next weave is used in setting up the linked list during the decoding phase. Current end and Current pick are used to store the value of the current location under consideration.

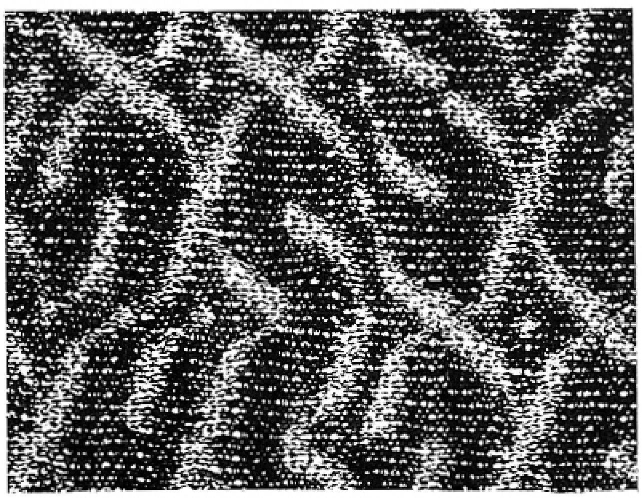
Decode - The interpreter part of the program has two functions; to set up the linked list, current weave, and to partially fill the list of associated parameters. All weave descriptor strings are first read into a buffer, *IN*, and a number of separate strings can be entered at one time. The strings are separated by a semi-colon, which not only delimits the separate strings but also terminates the decoding process for each string. The explicit actions of decode are shown in the accompanying flow chart.

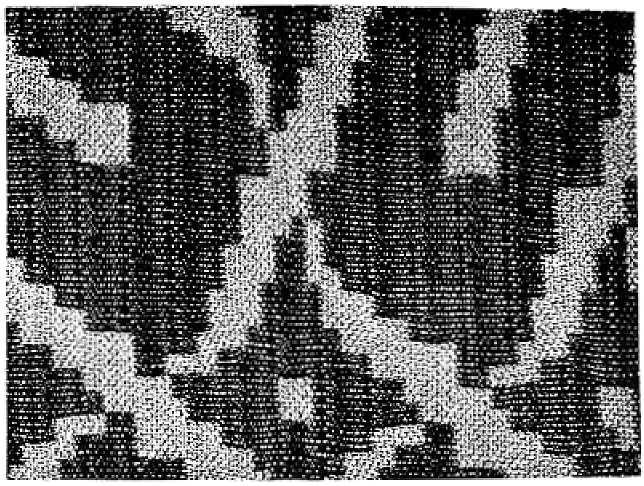
Perform - This is a two pass program. On the first pass the preambles of the weave algorithms which generate the weave dimensions are performed and the dimensions are placed in the appropriate locations in the operational parameter list and the address in current weave is changed to point to the function portion of the algorithm. The second pass is a pair of nested loops; the outer loop counting the number of the row under consideration and the inner loop counting the column. Each pass through the inner loop places either an X or a _ in the output buffer, *Out*, according to whether the value of the weave function is 1 or 0 and each pass through the outer loop prints the contents of the buffer as one line of the weave.

Weave Algorithms - The weave algorithms consist of two parts, one which generates the weave dimensions and an operational part which implements the function form of the weave. The general structures of these algorithms for the basic weaves, the single operators the parameter operators and the double operators is shown in flow chart form.

Flow Charts - In the flow charts the following notation is used extensively.

#A - use the address of A as a value.
A - use A as an address.
@A - use the contents of A as an address.
(A) - the contents of A.
$@A^{+} \rightarrow B$ - transfer the contents of the location that is pointed to by A into the address B then increment the contents of A.
$@^{-}A \rightarrow B$ - decrement the contents of A then transfer the contents of the location pointed to by A into B.





Push A - place (A)+2 into A.
Pop A - place (A)-2 into A.
A|B - concatinate the contents of A and B.
If WE is the name of a weave operator then WE will also stand for the symbolic address of the corresponding functional algorithm and WEP will stand for the symbolic address of the corresponding dimension algorithm.
ε - element of.
SO - the set of single operators.
DO - the set of double operators.
PO - the set of parameter operators.
WE - the set of basic weaves.

The following subroutines are used in the perform portion of the program :

FIX1 - sets the current weave pointer to point to the next location in the linked list, then uses the address pointed to to relocate the pointer.

FIX2 - returns the current weave pointer to its location prior to relocation by FIX1.

NORM - pushes the current end and current pick push downs, performs the calculations
(column number) mod (number of columns in weave)
(row number) mod (number of rows in weave)
then stores the results in the new locations in the respective push downs.

REPLACE - pops the current end and current pick push downs.

DO - causes a jump-to-subroutine to the address that is pointed to in the current weave list.

SET - associates the pointer, Oparm, with the current weave pointer, Curwe.

ADDITIONAL FEATURES

Weave Renaming

Justification - In the case of more complex weave structures the weave descriptor strings can become quite cumbersome. To enable the designer to write such strings with more facility and with less chance of error a facility is privided in the program to allow the designation of an entire, or partial, weave descriptor string by a two character name chosen by the user. This is done by preceeding the two characters by either the symbol / or the symbol ', writing the descriptor string as usual and following it by the symbol #. If the / character is used the string will be both saved and performed. If the ' character is used the string will be saved and not performed.

The Procedure - The two character names of the basic weaves and weave operators are stored in a list which is searched during the decoding phase if the program to determine the proper subroutine address to place in the current weave linked list. When either the / or ' character is encountered during the decoding process the two characters which follow are appended to the end of the list and a reference pointer, keyed to this position in the list of names, is generated to point to the first unused portion of the save area. The decoding process then continues, but a copy of the string is placed in the save area until a # is encountered. At this time an * is placed in the save area at the end of the string and the pointet to the first unused portion of the save area is set to this position. The decoding continues of there are further characters in the string and all succeeding characters are dumped as usual.

During any run of the program the renamed string may be retrieved by simply using the two character designation. When these characters are encountered in the decoding process the pointer to the current location in the input buffer is switched, temporarily, to the corresponding location in the save area and the decoding continues until an * is encountered, at which time the input pointer is shifted back to its location in the input string where the original shift was made. If the ' character is used a switch is set which prevents the Decode procedure from automatically switching to the Perform procedure when an ; is encountered.

The renaming procedure places the pointers which it generates in a push down so that substrings of strings which are neing renamed can also be renamed. Previously renamed strings can be used in strings being renamed and under certain circumstances partial weave operators can be renamed. This is quite useful in the case of the row or column transposition operators which often contain long lists of numeric parameters.

Examples - If the following series of input strings are entered: /X1TW(3,2,1,1)#;/X2TW(2,3,1,-1)#;/X3HC(X1,X2)#;/X4HC(X2,X1)#;VC(X3,X4); the program will generate and output:

```
TW(3,2,1,1)
TW(2,3,1,-1)
HC(TW(3,2,1,1),TW(2,3,1,-1))
HC(TW(2,3,1,-1),TW(3,2,1,1))
VC(HC(TW(3,2,1,1),TW(2,3,1,-1)),HC(TW(2,3,1,-1
),TW(3,2,1,1)))
```

If /WACT(1,1,2,2,2,3,3,3,3,4,4,5,6:#TW(1,5,1,1)); /WBRT(1,1,2,2,2,3,3,3,3,4,4,5,6:TW(4,2,1,1))#; WAWB); were input the program would generate and output;

```
CT(1,1,2,2,2,3,3,3,3,4,4,5,6:TW(1,5,1,1))
RT(1,1,2,2,2,3,3,3,3,4,4,5,6:TW(4,2,1,1))
CT(1,1,2,2,2,3,3,3,3,4,4,5,6:RT(1,1,2,2,2,3,3,3,3,4
,4,5,6:TW(4,2,1,1)))
```

Automatic Chain and Draw Operations

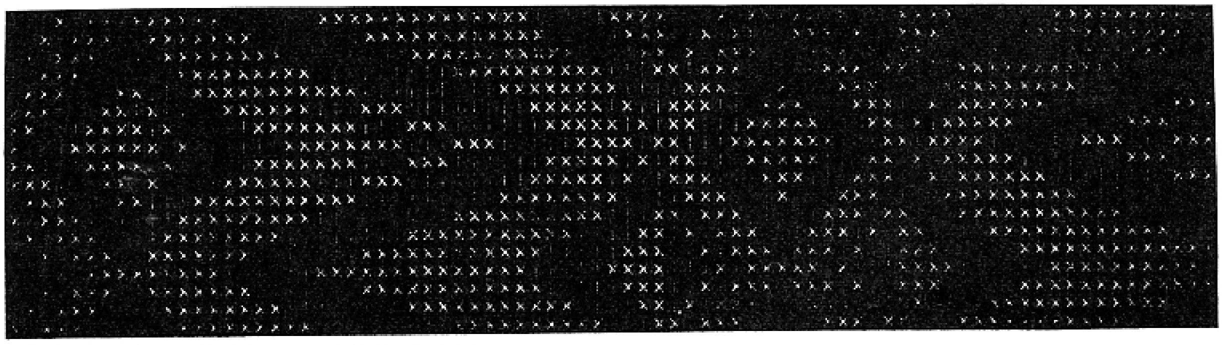
Need and Operators - On a harness loom the actual control of the operation is achieved through the *draw*; the order in which the various warp yarns are passed through the heddles on the various harnesses and the *chain*; the control device which selects the order in which the harnesses are to be raised. Once a weave is created it is often a laborious and error prone task to create the corresponding draw and chain. To alleviate the necessity of the desiqner's concern in this matter the program also includes the operators CH(W) which will generate a chain for the weave and DR(W) which will generate the corresponding draw.

Properties of the Chain and Draw - When considered as matrices, the weave, the chain and the draw are related. In fact the weave is the usual row by column matrix product of the chain by the draw. The matrix product operation is denoted by LP hence in weave language notation W = LP(C,D). Even though the draw matrix is not, in general, square, it does have the property that its transpose is its inverse. Thus given a weave and a draw, the chain, if one exists, is given by the relation C = LP(W,TP(D)). This is a very valuable tool for the textile designer.

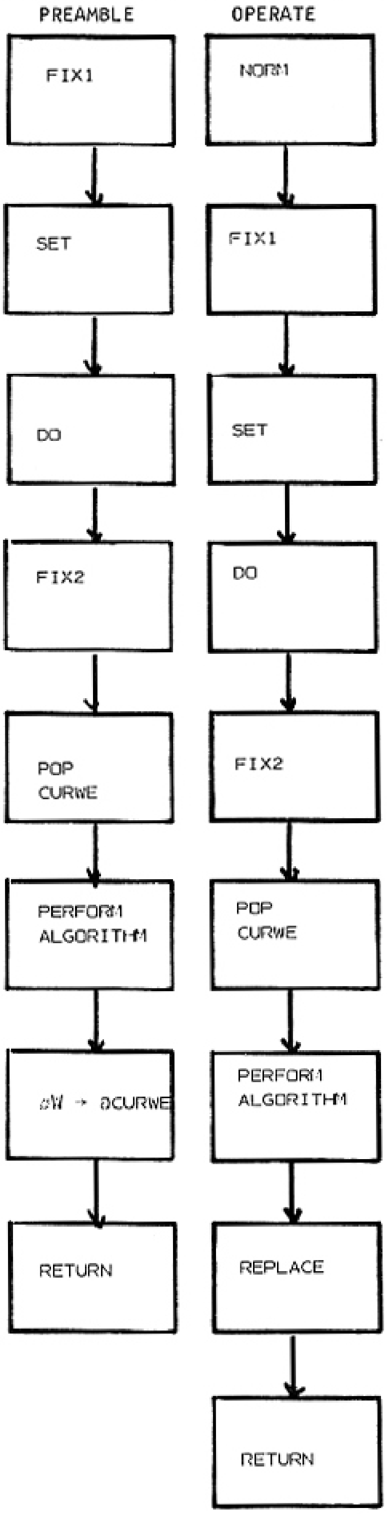
Conclusion

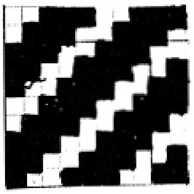
One of the major advantages to be gained from using the weave language program is of course speed. Not only does this allow for the production of rather complex designs in a matter of minutes, which would ordinarily require several hours to execute by hand, but it also encourages the designer to make changes which may improve an already good design, which ordinarily would not be made. In addition the rapidity of the through-put also encourages the designer to create more designs as well as more complex designs, as the time required to produce them has become a minor consideration.

The program is currently implemented on a PDP-11/20 computer having 16 K of core. It has been in use for two years, with great success, as a teaching tool in the textile design curriculum. One of the major advantages of the use of computer generated weave structures is that the student, or designer, is freed from the consideration of the mechanics of producing the design and can thus concentrate on the aesthetic appeal and functionality of the design.



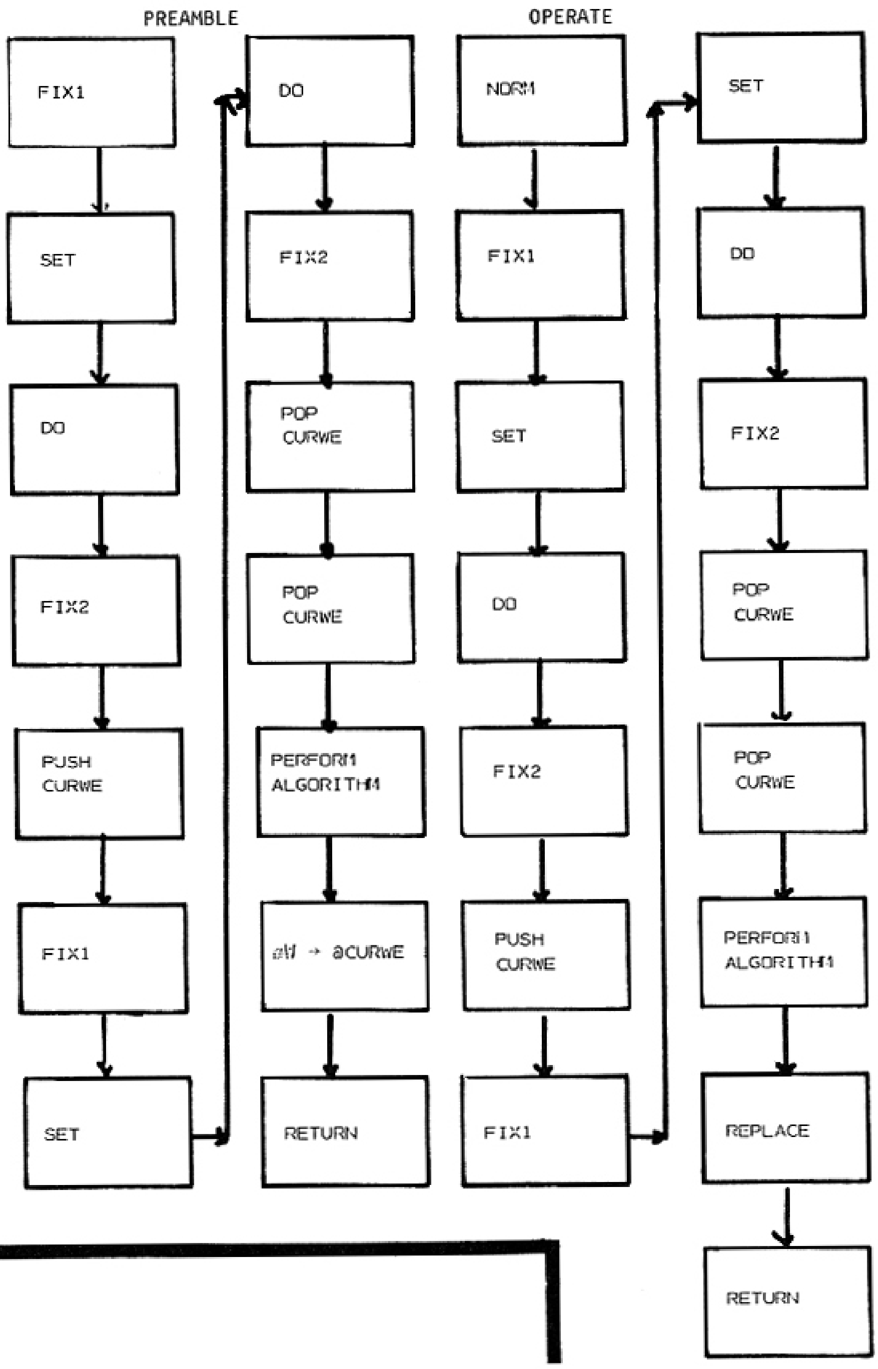
SINGLE AND PARAMETER OPERATOR SUBROUTINE





Point Paper Representation of $\frac{3}{2}$ 45° Right Hand Twill

DOUBLE OPERATOR SUBROUTINES



FROM STYLUS TO LIGHT PEN:
TECHNOLOGY AND INNOVATION IN THE DEVELOPMENT OF QUANTITATIVE GRAPHICS

by James R. Beniger
University of California
Survey Research Center
Berkeley, California 94720

Since the earliest recorded history, human beings have used pictures and other abstract graphics in the continuing struggle to understand — in a quantitative way — the world around them. In the clay maps of Babylonian explorers, the coordinate systems of Egyptian surveyors, and the musical notation of Vedic hymnists, humankind celebrated early triumphs in quantification and visualization of the abstract. Whether through counting, measurement, analysis or communication, visual images and numbers have repeatedly served, side by side, in the historical development of modern science. If mathematics is truly the Queen of Science, as so often stated, then quantitative graphics must certainly rank among her most valuable handmaidens.

Today, computer graphic technologies provide an unrivaled opportunity to expand this capability for visualizing the abstract phenomena of science and society. The CRT terminal and light pen may become, in the hands of the future scientist, what the clay tablet and stylus were to the ancient Mesopotamian.

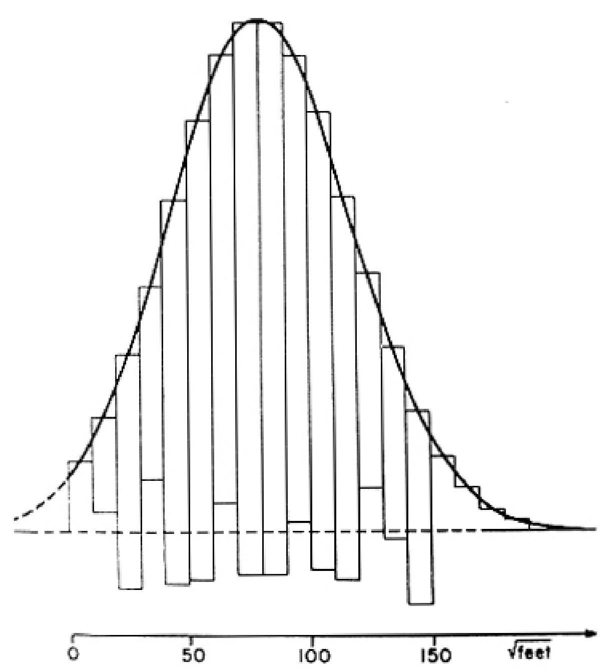
Before this latest revolution in visualizing media can be complete, however, the progress in analysis and communication technology must be matched by progress in quantitative graphic symbolization. Television news, for example, began as the televising of a radio news format, and has yet to tap the vast potential of computer graphics for dynamic statistical presentation. In the same way, computer graphics applications have tended to imitate earlier printer output, itself an imitation of printing press technology from the last century. Most of today's standard quantitative forms — like bar charts and line graphs, histograms and scatterplots — were commonplace a hundred years ago: none seem inherently suited to dynamic or interactive applications.

This research is sponsored, in part, by the National Science Foundation, Grant No. GS-29115. An earlier version of the chronology accompanied the author's slide presentation, "The History and Future of Graphics in Statistics," at the annual meetings of the American Statistical Association, Institute of Mathematical Statistics, and ENAR of the Biometric Society, Atlanta, Georgia, August 25-28, 1975. The author is indebted to A. D. Biderman, W. Kruskal, O. B. Sheynin, and S. Stigler for helpful comments on other versions of the work presented here.

In only the last dozen years or so have new quantitative forms, which exploit the technologies of modern computer graphics, begun to appear in the technical literature. As examples, one might cite Anderson's circular glyphs (see the year 1960), the triangles of Pickett and White (1966), the irregular polygons devised by Siegal and his collaborators (1971), Andrew's Fourier form for generating multivariate plots (1972), Chernoff's cartoons of human faces to represent multivariate data (1973), and the color-coded bivariate matrix used by the U.S. Bureau of the Census in recent maps (1974).

All of these graphic innovations are well-suited to computer applications and, conversely, none has much practical value except when executed by computer. With the exception of Tukey's various innovations for exploratory data analysis (1965, 1969), however, no recent innovation in quantitative graphics begins to exploit the interactive possibilities of computer graphics. The potential uses of dynamic, three-dimensional and colored graphics in quantitative applications remain largely unexplored.

BELOW: John Tukey's hanging rootogram, 1969.

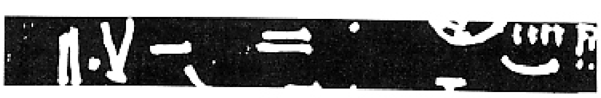


To illustrate the historical role of quantitative graphic innovation, in counterpoint to inventions in communication and computation, is the central purpose of this chronology. It lists the first known appearances of major graphic forms and techniques, along with innovations in printing, cartography, visual communication and computation, and related developments in mathematics, applied geometry and statistics. Little effort will be made to integrate such diverse developments, except to state that the author believes them to be integrally related, as he has attempted to show elsewhere (1, 2, 3). The intention here is rather to offer readers a more direct encounter with a still largely unresearched history, so that they might develop their own feel for the chaotic developments and interactions among quantitative graphic symbolization and technique, graphic technology and quantitative disciplines.

Readers interested in a more discursive history of quantitative graphics are referred to Funkhouser (4), which after 40 years remains the single best source on the subject, and also to the early handbook by Marey (5), from which Funkhouser borrows heavily. More recent treatments of certain 18th and 19th century developments may be found in Royston (6) and Tilling (7). The author's own work includes an overview of the subject, from the perspective of the sociology of knowledge (1), and a review of recent developments in statistics (3), particularly in exploratory data analysis (2). Primary sources that introduce particular graphic innovations have been listed in the body of the chronology itself.

Perhaps a brief note is in order concerning the usefulness, to historical analysis, of claims of so-called historical "firsts", since these repeatedly appear in the chronology that follows. It is relatively easy to establish that a given development is not first, simply by showing that the same innovation appeared still earlier. This will indicate either diffusion of the original innovation or independent invention. On the other hand, it will always be impossible to prove conclusively that any given innovation was an historical first, since contradictory evidence might turn up at any later date. It is for this reason that historians of science and knowledge have traditionally dodged claims of "firsts" for particular innovations.

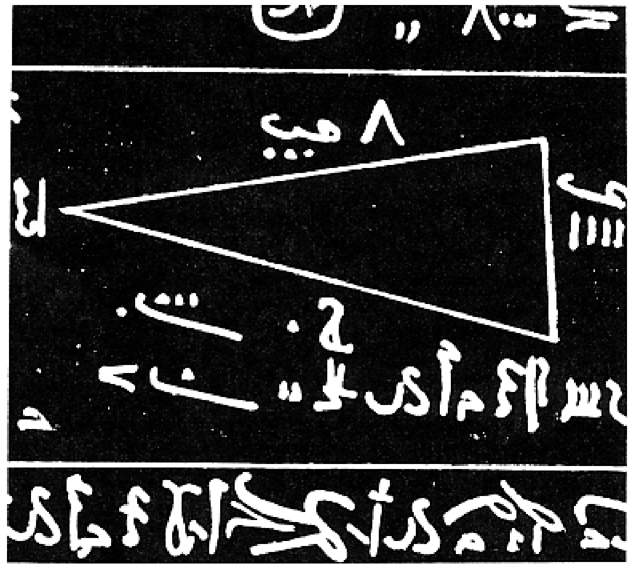
This chronology adopts just the contrary view, not only that innovations will be considered firsts until proved otherwise, but also that such a cavalier approach will greatly facilitate the progress of enlightenment. At least one precedent has long existed for this view: the various dictionaries (like The Oxford English Dictionary), which lists years for the earliest known occurrence of words and meanings. It appears that the very process of listing and publishing these dates hastens the progress of historical philology, since new evidence is continually submitted from the widest possible audience of readers. Much the same idea motivates the chronology here, which will certainly fail an important purpose if it does not draw a number of claims for earlier appearances of innovations, and for substantial additions to the listing.



CHRONOLOGY

c. 3200 B.C. — Coordinate systems to locate points in real space—Egyptian surveyors

c. 2400 B.C. — Map-making for land taxation—Sargon of Akkad (Babylonian), inscribed on baked clay



ABOVE: (Detail), Rhind Papyrus, discussion below.

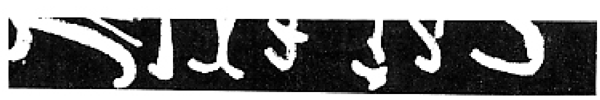
c. 1500 B.C. — Systematic guide to practical problems of geometry arising in surveying, including graphic representations of area (rectangular, trapezoidal, triangular and circular)—Scribe Ahmose (Egyptian), Rhind Papyrus, titled "A Guide to Accurate Reckoning into Things, Knowledge of Existing Things All", now in the British Museum

c. 500 B.C. — World map (showing Babylon at the center)—clay tablet, now in the British Museum

c. 330 B.C. — Treatise on conic sections—Aristotle (Greek)

c. 300 B.C. — Formal statement of geometric principles—Euclid (Greek), Elements

(NOTE: Due to limitations of space, the "full" Chronology has been edited to reveal some of the important firsts in the development of quantitative graphics. Readers interested in the definitive Chronology may write the author.)



ABOVE: Also by Albrecht Durer, "The Northern Hemisphere of the Celestial Globe." The two maps are geographical works designed by Durer for Johann Stabius. In 1497 Stabius left Ingolstadt and took up his residence in Vienna as Professor of mathematics and became court astronomer to the Emperor. (Both Durer works are from the text by Willi Kurth.)

4th century B.C. -Terrestrial and celestial globes—Eudoxus (Greek astronomer), now in the Naples Museum

c. 330 B.C.-Treatise on conic sections—Aristotle (Greek)

c. 300 B.C.-Formal statement of geometric principles—Euclid (Greek), Elements

c. 150 A.D.-Cartography as science, guide to charting world maps—Ptolemy (Alexandrian), Geography

c. 500-1500 A.D. -During the Middle Ages, despite the contributions of Ptolemy to cartography, maps remained diagrammatic. One of the best known examples is the "T-O" map, a circle with a "T" inside of it. The left half of the bar represented the Danube River, the right half the Nile, and the riser represented the Mediterranean. Asia was the top space, Europe the bottom left, and Africa the bottom right, and the Ocean surrounded the world as an "O". T-O maps were used into the 16th century.

11th cent. A.D. -Printing with movable type—Pi-Sheng (Chinese)

c. 1024 A.D.-Staff notation in music—Guido D'Arezzo (Benedictine monk)

10-11th cent. A.D. Curves on time grid (planetary orbits)—unknown transcriber of commentary on Macrobius on Cicero's In Somnium Scipionis

c. 1350 A.D. Proto-bar graph (of theoretical function)—Nicole Oresme (French mathematician)

early 17th Tables of empirical data—Die Tabellen-Statistik (Germany)

c. 1620 A.D. Systematic graphic computation with scale of numbers (forerunner of slide rule, nomography)—Edward Gunter (English astronomer)

c. 1637 A.D. Analytic geometry, relation between curve and equation—René Descartes (French)

c. 1686 A.D. Bivariate plot of observations (barometric reading vs. height), graphical analysis of empirical data--Edmund Halley (English)

c. 1693 A.D. Mortality tables--Edmund Halley (English)

c. 1701 A.D. Isobar map (lines of equal magnetic declination for world)--Edmund Halley (English)

c. 1733 A.D. Equation for normal probability curve--Abraham De Moivre (English)

c. 1748 A.D. Word "Statistik"--Gottfried Achenwall (German)

c. 1752 A.D. Contour map--Phillippe Buache (French)

c. 1761 A.D. Hypothetical mortality curves--J. L. D'Alembert (French mathematician)

c. 1765 A.D. Historical time line (life span of 2,000 famous people, 1200 B.C.-1750 A.D.); quantitative comparison by means of bars--Joseph Priestly (English chemist)

c. 1775 A.D. Geological map (showing distribution of soils, minerals)--Charpentier (French)

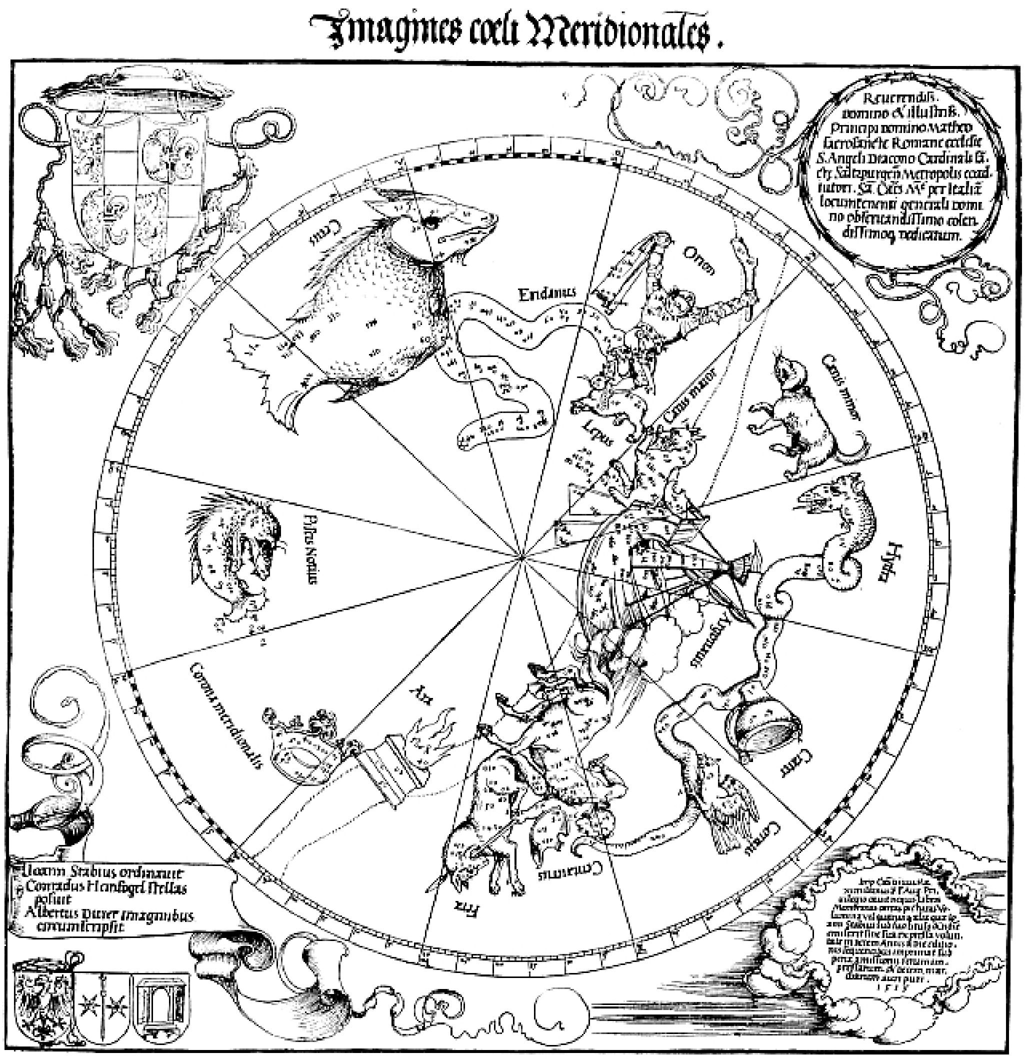
c. 1782 A.D. Statistical map--A. W. F. Crome (Professor of Political Economy and Statistics, University of Giessen, Germany), *Producten-Karte van Europa*

c. 1786 A.D. Bar graph--William Playfair (English), *Commercial and Political Atlas*

c. 1787 A.D. Word "statistics"--E. A. W. Zimmerman (English), *Political Survey of the Present State of Europe*

c. 1794 A.D. Printed coordinate paper--a Dr. Buxton (English)

BELOW: A woodcut designed by Albrecht Durer in the service of the Emperor Maximilian, "The Southern Hemisphere of the Celestial Globe" date 1515. Reduced in size, first block and impression at Munich. From the text, "The Complete Woodcuts of Albrecht Durer" edited by Dr. Willi Kurth, 1963, Dover Publications, NYC.



c. 1795 A.D. Multi-number graphical calculation (applied contours to multiplication table)—Louis Ezéchiel Pouchet (French manufacturer)

c. 1800 A.D. Use of coordinate paper in published research (graph of barometric variations)—Philosophical Magazine, Vol. 7, p. 357

c. 1801 A.D. Pie chart, circle graph—William Playfair (English), Statistical Breviary

c. 1811 A.D. Subdivided bar graph, superimposed squares—F. H. Alexander von Humboldt (German), Essai Politique sur le Royaume de la Nouvelle-Espagne

c. 1819 A.D. Cartogram (map with shadings from black to white, showing distribution and intensity of illiteracy in France)—Charles Dupin (French geometer, statistician)

c. 1821 A.D. Cumulative frequency curve or ogive (showing inhabitants of Paris by age groupings for 1817 —J. B. J. Fourier (French)

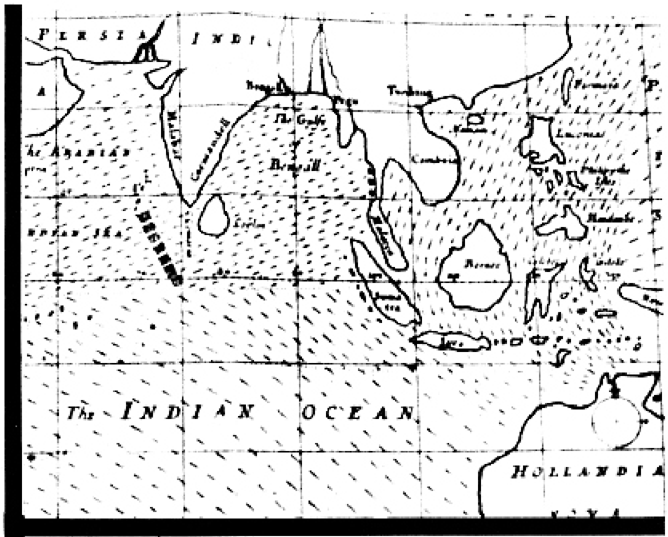
c. 1823 A.D. Digital calculator, "Difference Engine," discussed in terms of "programming" and "taping", and generally considered to be the first modern mathematical machinery—Charles Babbage (English)

c. 1825 A.D. Gompertz or "simple growth" curve ($l_x = Kg^{q^x}$)—Benjamin Gompertz (English actuary)

c. 1828 A.D. Mortality curves drawn from empirical data (for Belgium and France) —Adolphe Quetelet (Belgian statistician)

c. 1831 A.D. Graph of frequency distribution—Adolphe Quetelet (Belgian statistician)

c. 1833 A.D. Histogram (crimes by age groupings, and by months)—A. M. Guerry (French Statistician)



ABOVE, RIGHT AND BELOW, LEFT: Details of a Map of the World by Edmund Halley, 1701, from the text by Gustav Hellmann, 1895.

c. 1838 A.D. Published graph of normal curve—Augustus De Morgan (English probabilist), An Essay on Probabilities, and on Their Application to Life Contingencies and Insurance Offices

Logistic curve ($\frac{K}{1 + Ce^{rt}}$, where y denotes population, t denotes time, and K, C and r are constants) —P. F. Verhulst (Belgian mathematician)

c. 1840 A.D. Graphic time table (rail time vs. distance, with pivotal bar to determine speed)—M. Ibray (French engineer)

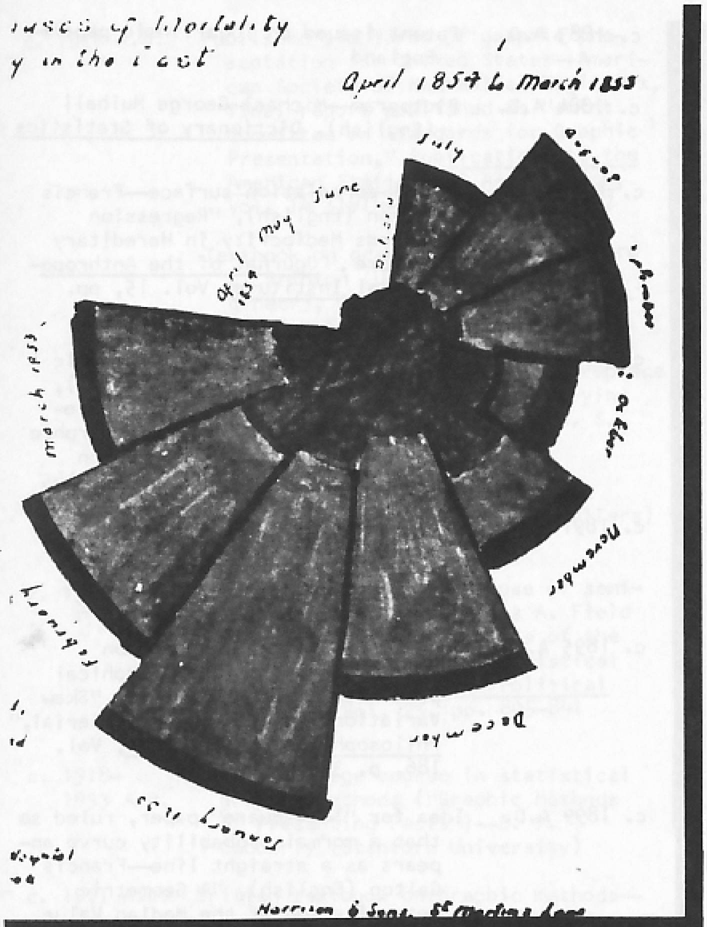
c. 1841 A.D. Graph in Journal of London Statistical Society (established 4 years earlier)

c. 1843 A.D. Logarithmic grid—Léone Lallane (French engineer), paper presented to the French Academy of Sciences

Polar coordinates (frequency of wind directions)—Leon Lalanne (French engineer), Cours Complet de Météorologie de L. F. Kaemtz (1845)

Contour map of table (temperature, hour x month)—Leon Lalanne (French engineer), Cours Complet de Météorologie de L. F. Kaemtz (1845)

c. 1845 A.D. Flow map, with band-width proportional to amount of traffic—Charles Joseph Minard (French engineer)



ABOVE: (Detail of Chart) — Polar area charts, known as "coxcombs"--Florence Nightingale (English), Mortality of the British Army, anonymous publication in the

c. 1857 A.D. — campaign to improve sanitary conditions of the army

c. 1863 A.D. — Semi-logarithmic grid (showing percentage changes in commodities)--Stanley Jevons (English), A Serious Fall in the Value of Gold Ascertained, and its Social Effects Set Forth, with Two Diagrams

Cartogram published in the United States--Edward Atkinson (U. S.), Report to the Boston Board of Trade on the Cotton Manufacture of 1862

c. 1868 A.D. — Statistical diagrams in a school textbook (geography)--Emile Levasseur (French), La France, avec ses Colonies

c. 1869 A.D. — Three-dimensional population surface (with axonometric projection to show curves of various "slices")--Gustav Zeuner (Germany)

c. 1872 A.D. — U. S. Congressional appropriation for graphic treatment of statistics

Use of statistical graphics by the U. S. government in census reports (cartograms of data from Ninth Census)--Statistics of Wealth and Public Indebtedness

c. 1846 A.D. — Published weather map--Elias Loomis (U. S.), "On Two Storms Experienced Throughout the United States in the Month of February, 1842," Transactions of the American Philosophical Society, Vol. 9, pp. 161-184

Results of urn schemata as symmetrical histogram, with limiting normal curve--Adolphe Quetelet (Belgian statistician)

c. 1847 A.D. — Statistical map (tone wash) in Journal of London Statistical Society (shows sectors of England and Wales)

c. 1851 A.D. — Map incorporating statistical diagrams (circles proportional to coal production)--Charles Joseph Minard (French engineer)

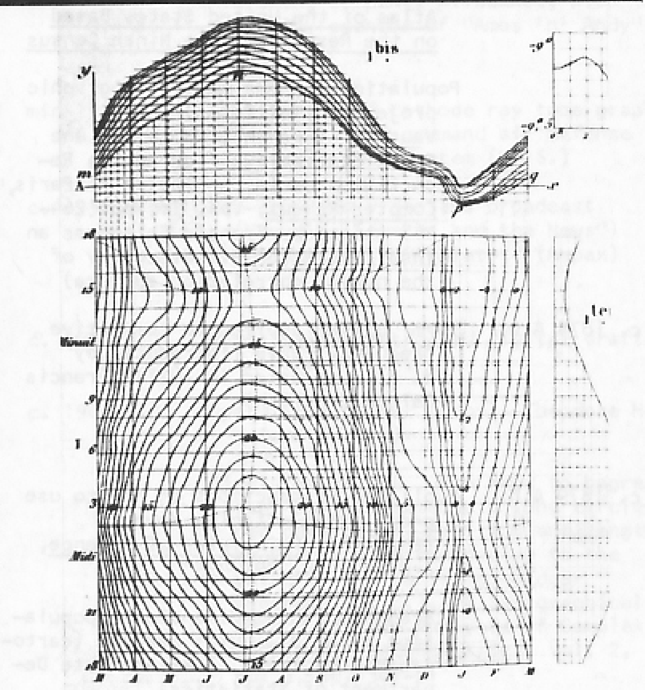
c. 1852 A.D. — Graphics used in lawsuit--Germany

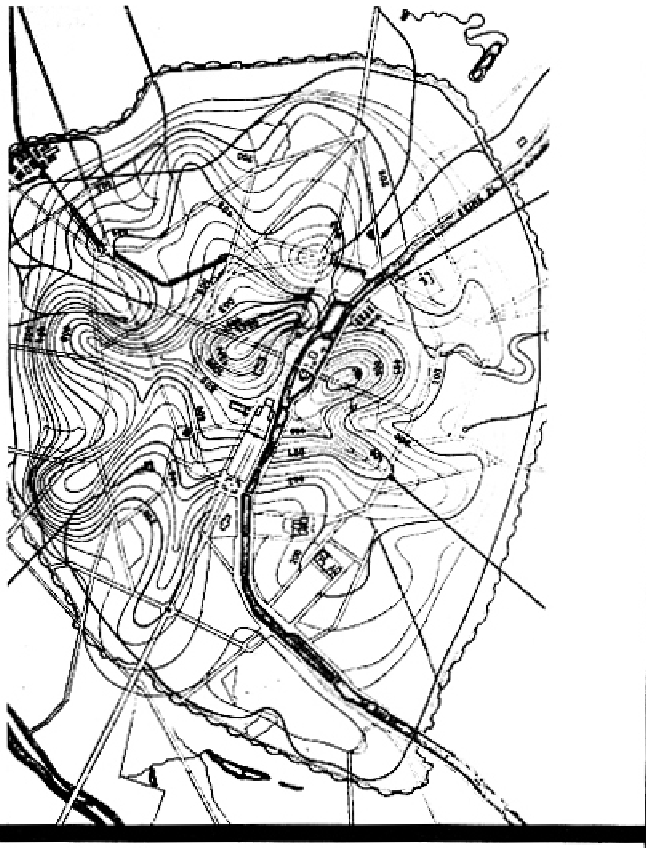
c. 1857 A.D. — Discussion of graphic methods before International Statistical Congress--Third (Vienna)

Use of statistical graphics by U. S. government in census reports (cartograms of data from Ninth Census)--Statistics of Wealth and Public Indebtedness

Classification of statistical graphic treatments by form--H. Schwabe (Chief of Municipal Bureau of Statistics, Berlin), "Theorie der Graphischen Darstellugen," Congres International de Statistique, pp. 61-73

BELOW: First Contour Map of a Table (Mean Temperature, Hour x Month) by Leon Lalanne, 1843.





ABOVE: Statistical Contour Map of the Population of Paris by L. L. Vauthier, 1874, from the text by Marey, Paris, 1878.

c. 1874 A.D. Age pyramid (bilateral histogram), bilaterial frequency polygon—Francis A. Walker (Superintendent of U. S. Census), Statistical Atlas of the United States Based on the Results of the Ninth Census

Population contour map (orthographic projection, of Paris)—L. L. Vauthier (French), "Note sur une Carte Statistique Figurant la Repartition de la Population de Paris," Comptes Rendus, Vol. 78, pp. 264-267 (cited by Francis Galton as an inspiration for his discovery of the normal correlation surface)

c. 1875 A.D. Term "ogive" applied to cumulative frequency curve (introduced by J. B. J. Fourier in 1821)—Francis Galton (English)

c. 1879 A.D. Published instructions on how to use graph paper—Stanley Jevons (English), Principles of Science, 3rd Ed., pp. 492-495

Stereogram (three-dimensional population pyramid)—Luigi Perozzo (cartographic engineer, Italian State Department of Statistics)

c. 1883 A.D. Patent issued on logarithmic paper—England

c. 1884 A.D. Pictogram—Michael George Mulhall (English), Dictionary of Statistics

c. 1885 A.D. Normal correlation surface—Francis Galton (English), "Regression towards Mediocrity in Hereditary Stature," Journal of the Anthropological Institute, Vol. 15, pp. 246-263

c. 1888 A.D. Correlation coefficient by graphic means—Francis Galton (English), "Co-relations and Their Measurement, Chiefly from Anthropomorphic Data," Royal Society of London Proceedings, Vol. 45, pp. 135-145

c. 1891 A.D. Word "nomography" Maurice D'Ocagne (Ecole Polytechnique, Paris), Nomographie, Les Calculs Usuels Effectues au Moyen des Abaques

c. 1895 A.D. Word "histogram"—Karl Pearson (English), lectures on graphical presentation in statistics; "Skew Variations in Homogeneous Material," Philosophical Transactions, Vol. 186, p. 399

c. 1899 A.D. Idea for "log-square" paper, ruled so that a normal probability curve appears as a straight line—Francis Galton (English), "A Geometric Determination of the Median Value of a System of Normal Variants from Two of its Centiles," Nature, Vol. 61, pp. 102-104

c. 1905 A.D. Lorenz curve—M. O. Lorenz (U. S.), "Methods of Measuring the Concentration of Wealth," Publications of the American Statistical Association, Vol. 9, pp. 209-219

c. 1910 A.D. Statistical diagrams in U. S. textbooks (graphs of temperature, population, in texts of arithmetic, algebra)

c. 1913 A.D. Arithmetic probability paper, ruled so that a cumulative normal probability curve (ogive) appears as a straight line (applied to problems of surface drainage)—Allen Hazen (U. S.), "Storage to be Provided in Impounding Reservoirs for Municipal Water Supply," Transactions of the American Society of Civil Engineers, Vol. 77, (1914), pp. 1539-1669. Read December 17, 1913

c. 1913-1914 A.D. College course in statistical graphic methods—M. F. P. Costelloe (Dept. of Agricultural Engineering, Iowa State College)

c. 1914 A.D. Published standards of graphic presentation for United States—American Society of Mechanical Engineers, final report published as "Joint Committee on Standards for Graphic Presentation," Publications of the American Statistical Association, Vol. 14 (1914–1915), pp. 790–797

Textbook on graphic methods—Willard C. Brinton (U. S. mechanical engineer), Graphic Methods for Presenting Facts

Pictograms of uniform size (to replace bar graphs, pictograms of varying size)—Willard C. Brinton (U. S. mechanical engineer)

c. 1916 A.D. Correspondence course in graphic methods (20 lessons, fifty dollars) —Frank J. Warne (U. S.)

c. 1917 A.D. Published exposition of use of semi-logarithmic paper—James A. Field (U. S.), "Some Advantages of the Logarithmic Scale in Statistical Diagrams," Journal of Political Economy, Vol. 25, pp. 805–841

c. 1918–1933 A.D. Yearly college course in statistical graphic methods ("Graphic Methods of Presenting Facts")—E. P. Cubberly (Stanford University)

c. 1921 A.D. British textbook on graphic methods—A. R. Palmer (English), The Use of Graphs in Commerce and Industry

c. 1924 A.D. Social statistical graphics museum—Social and Economic Museum, Vienna (Otto Neurath, Director)

c. 1931 A.D. "Log square" paper—F. C. Martin and D. H. Leavens (U. S.), presented in "A New Grid for Fitting a Normal Probability Curve to a Given Frequency Distribution," Journal of the American Statistical Association, Vol. 26, pp. 178–183

c. 1933 A.D. Standard statistical symbols established by government decree—Soviet Union (for schools, public posters)

c. 1937 A.D. Three-dimensional cinematography ("Viterama")—Frederick Waller

c. 1938 A.D. Xerographic copy produced—Chester F. Carlson (U. S.)

c. 1941 A.D. Commercial television broadcast—WNBT, New York

c. 1945 A.D. Electronic digital computer (containing 18,000 radio tubes)—ENIAC, J. Presper Eckert and John W. Mauchly, University of Pennsylvania, for U. S. Army Ordinance Department (kept in service for ten years)

to			
8	0	98766562	0 | 9 = 900 feet
16	1	97719630	
39	2	69987766544422211009850	
57	3	876655412099551426	
79	4	9998844331929433361107	
102	5	97666666554422210097731	
(18)	6	898665441077761065	
98	7	98855431100652108073	
78	8	653322122937	
66	9	377655421000493	
51	10	0984433165212	
38	11	4963201631	
28	12	45421164	
20	13	47830	
15	14	00	
13	15	676	
10	16	52	
8	17	92	
6	18	5	
5	19	39730	19 | 3 = 19,300 feet

ABOVE: Stem and leaf displays — heights of 218 volcanoes, unit 100 feet.

(Source: The World Almanac, 1966 (New York: World-Telegram and the Sun, 1966.)

c. 1945 A.D. Phototypesetting machine—E. G. Klingberg, Fritz Stadelmann and H. R. Freund (U. S.)

c. 1948 A.D. Xerography process announced—Chester F. Carlson (U. S.)

Polaroid Land camera—Edwin H. Land (U. S.)

Holographic principles outlined—Dennis Gabor (English)

c. 1953 A.D. Statistical graphic (bar chart) in television commercial—Blatz Brewing Company, Milwaukee, Wisconsin, sponsor of "Amos 'n' Andy"

mid-1950's A.D. Application of cathode ray tube graphic terminals (to command air defense system)—SAGE System (U. S.)

c. 1956 A.D. Pre-recorded videotape broadcast ("Douglas Edwards and the News") —Alexander M. Poniatoff (Ampex)

c. 1958 A.D. Numerically-controlled digital drafting machine—M.I.T.

c. 1960 A.D. Operational laser (ruby)—Theodore H. Maiman (U. S.)

Circlular glyphs, with rays to represent multivariate data (one circle per data point, position and length of each ray corresponding to the value of one variable)—Edgar Anderson (U. S.), "A Semigraphical Method for the Analysis of Complex Problems," Technometrics, Vol. 2, No. 3, pp. 387–91

c. 1962 A.D. Use of cathode ray tube graphic terminals in non-military environment--Ivan E. Sutherland, "Sketchpad: A Man-Machine Graphical Communication System," M.I.T. Lincoln Laboratory, Lexington, Mass., published 1963

c. 1963 A.D. Computer-aided design using CRT graphic terminals--DAC-1 System, General Motors

c. 1964 A.D. Videotelephone ("Picturephone") service--Bell Telephone System, linking New York World's Fair and Disneyland, California

c. 1965 A.D. Improvements on histogram in analysis of counts, tail values--John W. Tukey, "The Future of Processes of Data Analysis," U. S. Army Research Office Report 65-3, pp. 691-729

c. 1966 A.D. Triangles to represent simultaneously four variables, using the sides and orientation--R. Pickett and B. W. White, "Constructing Data Pictures," Proceedings of the 7th National Symposium for Information Display, pp. 75-81

c. 1968 A.D. Simulation of a chemical reaction by visual display on a computer--Enrico Clementi (U. S.)

Laser printing ("Laserfax")--Kenneth H. Fischbeck (U. S.)

Glassy material electronic components --Stanford R. Ovshinsky (U. S.)

c. 1969 A.D. Graphic innovations for exploratory data analysis (stem-and-leaf, graphic lists, box-and-whisker plots, two-way and extended-fit plots, hanging and suspended rootograms)--John W. Tukey, "Some Graphic and Semigraphic Displays," first presented at annual meeting of the American Statistical Association

c. 1971 A.D. Irregular polygon to represent multivariate data (with vertices at equally-spaced intervals, distance from center proportional to the value of one variable)--J. H. Siegel, R. M. Goldwyn and H. P. Friedman, "Pattern and Process of the Evolution of Human Septic Shock," Surgery, Vol. 70, No. 2, pp. 232-45

Proposal to use statistical graphics in social indicator reporting, particularly on television--Albert D. Biderman, "Kinostatistics for Social Indicators," Educational Broadcasting Review, Vol. 5, No. 5, pp. 13-19

c. 1972 A.D. Form of Fourier series to generate plots of multivariate data--D. F. Andrews, "Plots of High Dimensional Data," Biometrics, Vol. 28, pp. 125-36

Printed book with tables and graphs composed by computer, executed by computer plotter--Charles Lewis Taylor and Michael C. Hudson, World Handbook of Political and Social Indicators, Yale University Press, (Composed on IBM 7094-7040 DCS, listed by IBM 1401, graphs drawn by CalComp plotter; set in IBM Press Roman type)

c. 1973 A.D. Cartoons of human face to represent multivariate data (one face per data point), with each feature corresponding to one component of the point)--Herman Chernoff, "The Use of Faces to Represent Points in k-Dimensional Space Graphically," Journal of the American Statistical Association, Vol. 68, No. 342, pp. 361-368

U. S. Government chartbook devoted exclusively to social indicator statistics--Social Indicators 1973, Office of Management and Budget

Professional organization (pan-disciplinary) devoted to quantitative graphic analysis and communication--Council on Social Graphics, Washington, D.C.

c. 1974 A.D. Weekly chartbook (now computer-generated) to brief U. S. President, Vice President on economic and social matters--Bureau of Census and Office of Management and Budget, at request of Vice President Nelson Rockefeller

Color-coded bivariate matrix to represent two intervally-measured variables in a single map--U. S. Bureau of the Census and Manpower Administration, Urban Atlas series

Annual Conference on Computer Graphics, Interactive Techniques, and Image Processing--Association for Computing Machinery and SIGGRAPH, joint sponsors

Academy Award nomination, computer-animated film ("Hunger")--Peter Foldes, Marcelli Wein and Nestor Burtnyk, National Research Council of Canada

Dynamic cartogram (world map of oil production and consumption) in television commercial--Exxon Corporation

Cartoon of multivariate data analysis (relative strengths of teams and predictions in National Football League games) in nationally-syndicated column--Bud Goode, cartoon designed by Bernard Gruver, drawn by CalComp plotter, syndicated by United Press Features

c. 1975 A.D. "Three-dimensional" computer-generated maps to show distributions (by U. S. states) of persons listed in a directory—Harvard (University) Alumni Directory, maps by Mary Raymer, Harvard Mapping Service (Graduate School of Design)

c. 1975 A.D. Scholarly spoof of statistical graphic standards--"Picrocole Rashcalf et al,"--"Advanced Applications of the Theory of the Bar Chart," Journal of Irreproducible Results, Vol. 21, No. 4, pp. 2-3

c. 1976 A.D. U. S. Government series of chartbooks devoted exclusively to social indicator statistics—Social Indicators 1976—second volume in tradition of Social Indicators 1973, Office of Management and Budget

BELOW, LEFT: From the Laboratory for Computer Graphics and Spatial Analysis, Harvard University.

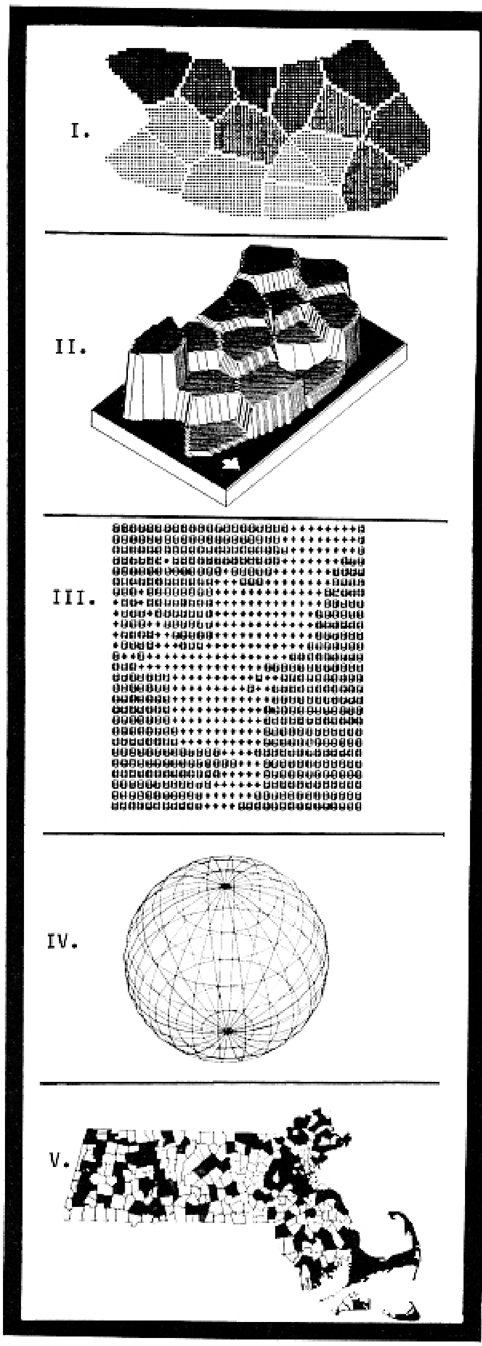
I. SYMAP: produces maps on a line printer showing spatially variable data. Contour, conformant, and proximal maps are produced.

II. SYMVU: generates 3-D line drawings of continuous surfaces on a pen or CRT plotter. Has hidden line removal and user definition of image size, vertical and horizontal rotation.

III. GRID: line printer dispalys. Uses an array of values which are categorized, assigned graphic symbols and displayed in map form.

IV. OTOTROL: 3-D line drawings of an object, such as an architectural structure, viewed from any point in space.

V. CALFORM: produces shaded conformant maps on a line plotter by using symbolism to represent data values associated with geographic areas.



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(1) James R. Beniger, 1975. Science's "Unwritten" History: The Development of Quantitative and Statistical Graphics. Paper presented to the Annual Meeting of the American Sociological Association, New York, 1976.

(2) ______________. 1976. Using Graphics to Explore Data. Paper presented to the Joint Washington Operations Research Council-The Institute of Management Sciences (Washington D.C. Area Chapter) Manpower Symposium, Washington, 1976.

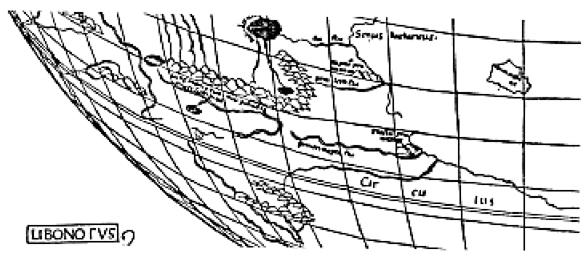
(3) James R. Beniger and Dorothy L. Robyn. 1976. The History and Future of Graphics in Statistics. Paper presented to the annual meetings of the American Statistical Association, Institute of Mathematical Statistics, and ENAR of the Biometric Society, Boston, 1976.

(4) H. Gray Funkhouser. 1937. Historical Development of Graphical Representation of Statistical Data. Osiris 3, 1:269-405.

(5) E. J. Marey. 1878. La methode graphique dans les sciences experimentales et principalement en physiologie et en medecine. Paris.

(6) Erica Royston. 1956. A Note on the History of the Graphical Presentation of Data. Biometrika 43, 3 & 4: 241:247; also reprinted in E. S. Pearson and M. G. Kendall. 1970. Studies in the History of Statistics and Probability Theory. London.

(7) Laura Tilling. 1975. Early Experimental Graphs. British Journal for the History of Science and Technology 8, 30: 193-213.



COMPUTER GRAPHICS AT THE UNIVERSITY OF MUNICH (WEST GERMANY)

by Reiner Schneeberger
8043 Unterfohring Kanalstr. 15
West Germany

"This is a report of the first computer graphics course for students of art at the University of Munich...A further objective to be realized was for every student to be able to generate esthetically appealing computer graphics after only the first lecture period."

INTRODUCTION

In the summer semester at the Universitat Munchen a course in the programming of computer graphics was carried out by the author in connection with a teaching commission under the Department of Art (Professor Hans Daucher).

Although the participants possessed no special technical skills or experience whatever in programming, the theoretical aspects of computer graphics and the computer arts were already known to them, since a course in Cybernetic Esthetics was regularly held in the same department by Dr. Herbert W. Franke.

An important factor was that only truly interested students registered for the course, and these students consequently participated in these sessions until the end without interruptions. The lecture met once weekly for two hours and consisted of ten instructional units. The duration of the course was set at approximately four months.

CONCEPTION AND OBJECTIVES

In the conception of the course, it was taken into consideration that none of the students had ever come in contact with the facilities of an Electronic Data Processing Center, and that only knowledge in basic mathematics, learned at the gymnasium was to be expected. Some difficulties were anticipated, since all the work could be carried on locally at the Computer Center, some ten kilometers distant from the instructional site.

The participants were expected to carry out their exercises independently, as no instructors were available during the periods between the course lectures, which met once weekly.

A further objective (and difficulty) was for every student to be able to generate esthetically appealing computer graphics after only the first lecture period.

AVAILABLE GRAPHICS SOFTWARE

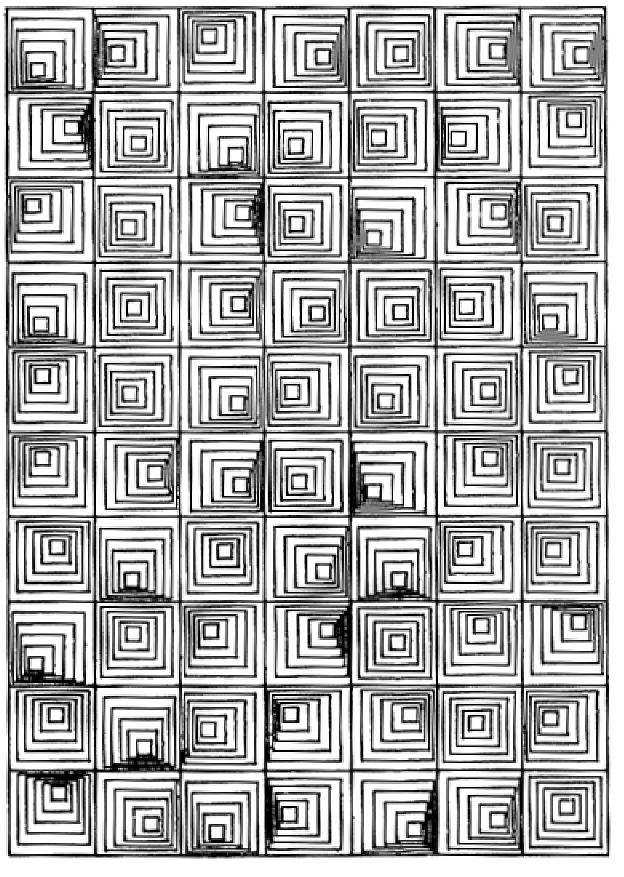
The graphics system from the Computer Center proved to be unsuitable for our purposes, since it employed a higher level program language (FORTRAN IV, ALGOL 50) — and to conduct lessons for art students in these languages would have been too exacting for them. The possibility was to develop an interface between the graphics system and the available BASIC Compilter Interpreter, creating an opportunity of treating the graphics software in the more simple BASIC language. This would not have changed the fact that a programming language would have to be learned from the beginning, but it would allow use of a programming language that was more suited to the artists' programmatic capacities.

GRAPHICS SYSTEM SNE COMP ART 76

In order to produce computer graphics demanding minimal programming knowledge, module technology was employed. Individual modules were chosen according to desired graph designs and skills of the users. The corresponding information was input into the computer through punched cards.

The input modules can therefore be temporarily modified by adding subroutines, thus creating unique program components (such as loops and dynamic parameter variations).

Figure 4 (BELOW) — SEE DESCRIPTION AT RIGHT.



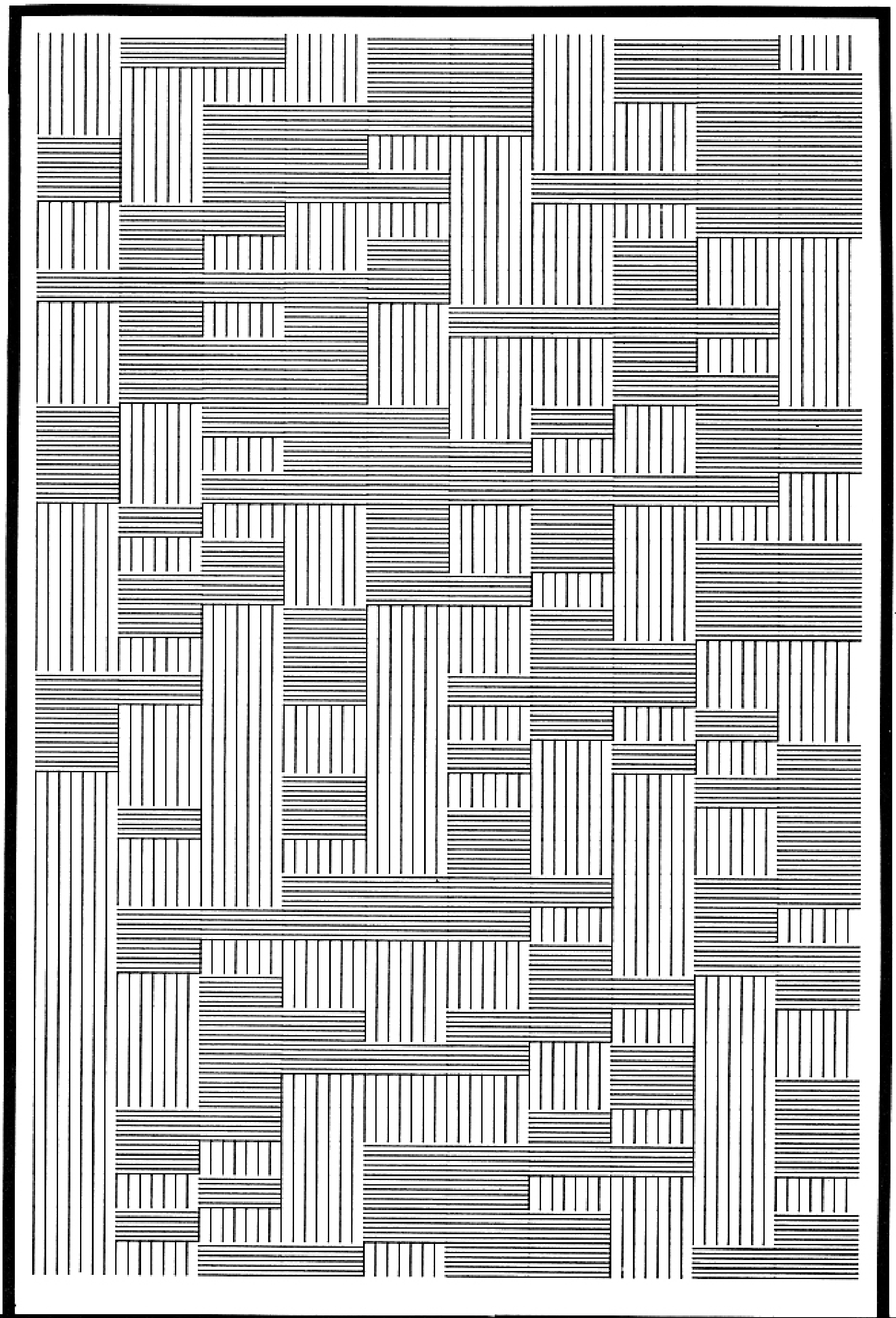


Figure 4 (OPPOSITE PAGE AT LEFT)

This picture was generated by the student of R. Stoiber. The middle point M(M1,M2) of each square was ascertained by chance.

M1 = SNERAD (A1,B1)
M2 = SNERAD (A2,B2)

SNERAD gives a probability value between A1, B1 and A2, B2 respectively, which pertain to M1, M2 respectively.

Figure 1 (ABOVE)

The program consists of three call orders:

1. Size of the sheet of paper.
2. A scale distortion of 1:2 in one direction.
3. The routine SNEKAO with eight parameters.

The routine SNEKAO proves here two elements: 1. ≡ 2. ||||. These squares occur in a random order. The scale distortion of 1:2 stretches the elements in on one direction to produce graying effects.

In the design of the system that we called SNE COMP ART 76, particular emphasis was placed upon the gradual transition from the use of pure modules (Figure 1) to genuine BASIC programming (Figure 2). The individual modules of the graphics system SNE COMP ART 76 can be dynamically controlled with minimal expertise (Figure 3) on the part of the user.

Moreover, additional external coincidence generators (random numbers) can be coupled to the individual modules (Figure 4).

At present, the graphics language comprises approximately ten complex modules (SNEKAO) and several function modules (SNERAD).

The dependence of command cards for winding up the individual system operations could be greatly reduced or completely eliminated with the help of internal sequence command calls.

DIDACTIC ASPECTS

The main purpose of the course was to enable the participants to create their own computer graphics. Individual base modules of the graphic language SNE COMP ART 76 are presented, which fulfill this purpose. Modules of increasing complexity were gradually employed, which provided a dynamic internal control of the individual subroutine parameters. In this way the first transition to the programming level was realized.

As the next step temporary variations of the individual submodules were described. So-called function modules, such as SNERAD (Figure 4) are used as additional aids. In this manner the step to pure programming was taken, by application of the two primary orders MOVETO and DRAWTO (Figure 2).

It was found that the concept of advancing from the complex modules to BASIC programming is an excellent method of introducing art students to practical computer graphics.

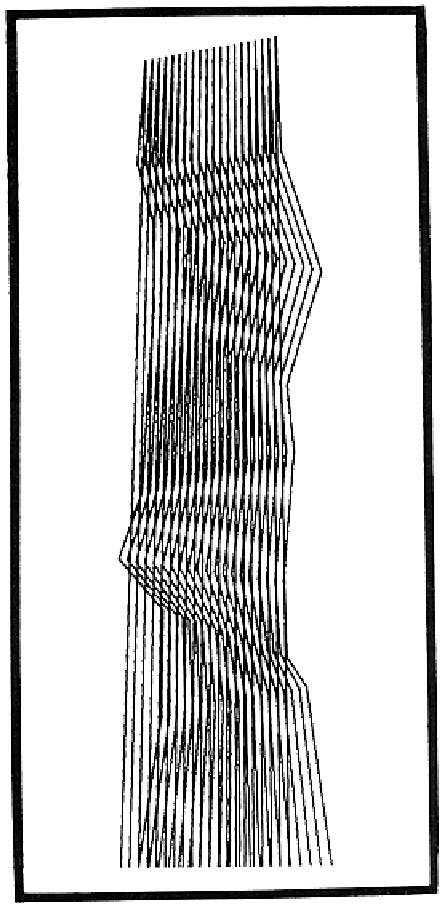
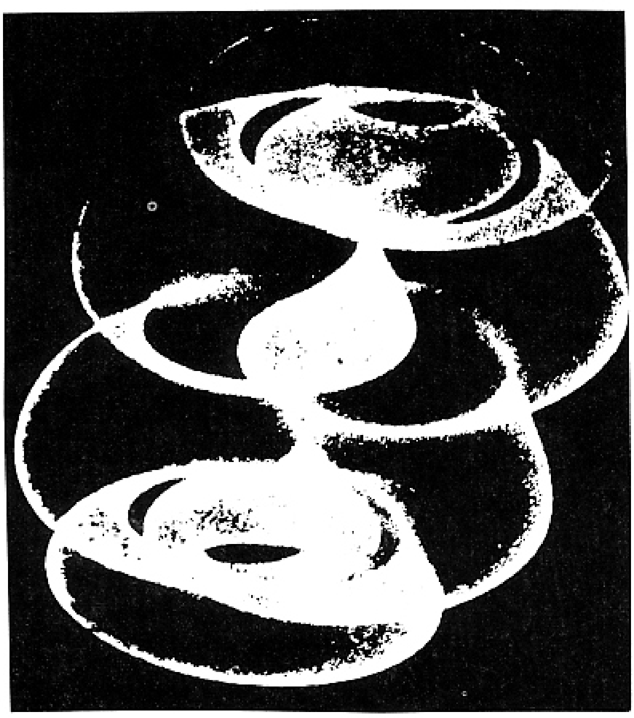


Figure 2 (ABOVE) - An example of BASIC programming by a student.



AT LEFT, BELOW - A silk-screened graphic by Herbert Franke. The original work was displayed on a cathode ray tube, and in the photographic development process, a coarse-grained screen was utilized to achieve a new look in CRT graphics. (See references for details.)

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Franke, Herbert W., "On Producing Graded Black and White or Color Computer Graphics in Combination with a Photographic Technique", Leonardo, Vol. 7, 1974, p. 333-335.

______________, Apparative Kunst, Cologne, Germany: DuMont Schauberg, 1974, 214 p.

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"Art Issue", Computer Graphics and Art, Vol. 1, No. 2, May, 1976.

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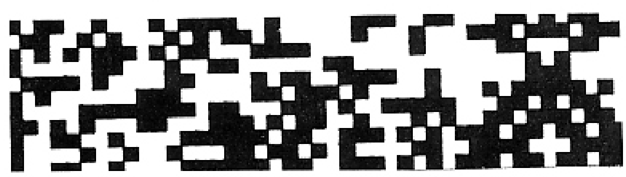


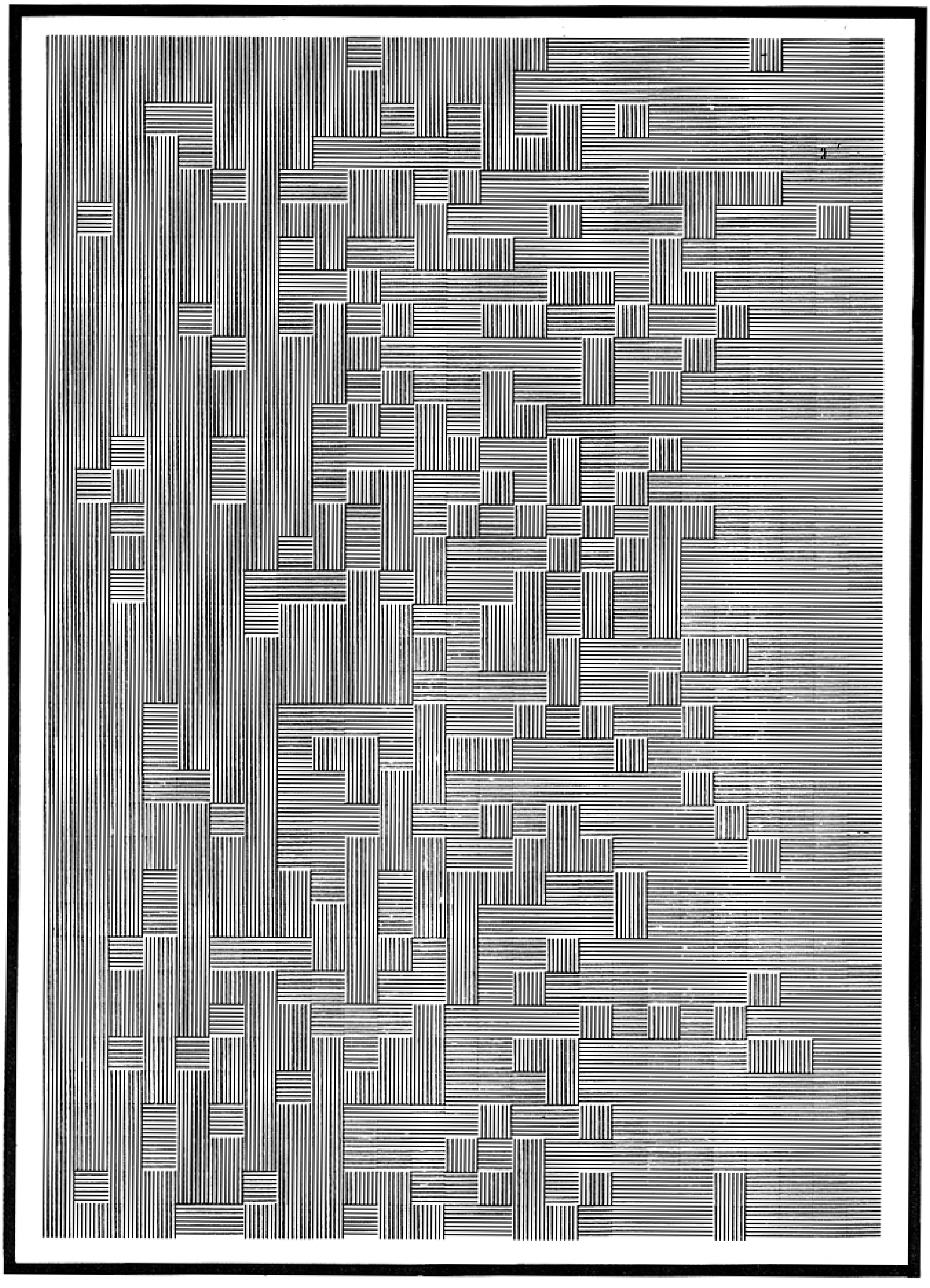


Figure 3 (ABOVE) - The routine SNEKAO is called once for each column, so that the proportion of horizontal and vertical elements per column is delivered in the form of two parameters. The employment of a programming loop here is particularly elegant. The graphic is an excellent example of the type of work produced by students in their first course at the Universitat.

NOTE: For readers desiring additional material on the teaching of computer art, see the Spring Bibliography Issues of Computers and the Humanities Magazine for definitive references on the Computer Visual Arts.

Added material is also given in the abstracts of the Biennial International Conferences of Computers and the Humanities. (See the Table of Contents for the announcement on the 1977 International Conference.)

COMPUTER-ASSISTED GRAPH-MAKING

by Elaine McNichols
Department of Computer Science
California State University, Chico
Chico, California 95929

"It quickly became apparent that a user-oriented graphing system was necessary for the general interdisciplinary student to use -- a system that would depart from the complex CalComp-based subroutines, such as AXIS, LINE, SCALE, and NUMBER."

BACKGROUND

A beginning system for graphical representation of data is briefly discussed. This system offers a variety of automated graph types, and is programmed with the average, non-computer oriented user in mind. The system allows flexibility within standardized forms, and includes such features as: default, forgiveness, options, standardized data formats, and transportability of data decks between programs.

THE VALUE OF GRAPHS

A simple line graph can convey to a large audience what a column of numbers never could. The more complex the data, the more valuable its graphical representation becomes. The broader, "forest instead of the trees" view provided by graphs and charts can be invaluable in data interpretation, and often allows new insights to be gained, especially if the data is graphed in more than one way.

MAKING A GRAPH

Unfortunately for most of us, making graphs, like painting the proverbial picture, is somewhat of an art: to be of maximum value, a graph must be scrupulously neat and precise. Drawing one by hand can take considerable time, and perhaps even talent. Therefore, most people find the task of constructing a chart or graph to be very time-consuming as well as difficult. Even the commercial aids now available (such as strips of tape with dotted lines or shaded bars) do not take the main burden of precision upon themselves -- it is up to the human to make sure the lines are straight, and that the peaks and valleys are precise.

COMPUTER-ASSISTED GRAPH-MAKING

My interest in computer-assisted graph-making began while taking a course in Interdisciplinary Graphics in 1973. I began working with biology-oriented bar graphs. Before that time I had used the plotter solely for art; however the more practical, useful aspects of computer-aided graph making appealed to the pragmatist in me. In graphing via the computer, I found the perfect blend of art and practicality.

Two years later, the Department of Computer Science expressed an interest in a "mini service course" of one unit for interdisciplinary students, to be called "Introduction to Graphing". Professor Grace Hertlein had prepared the syllabus, and had planned to teach the course originally. Because of class scheduling conflicts, the responsibility for teaching the course was passed on to me.

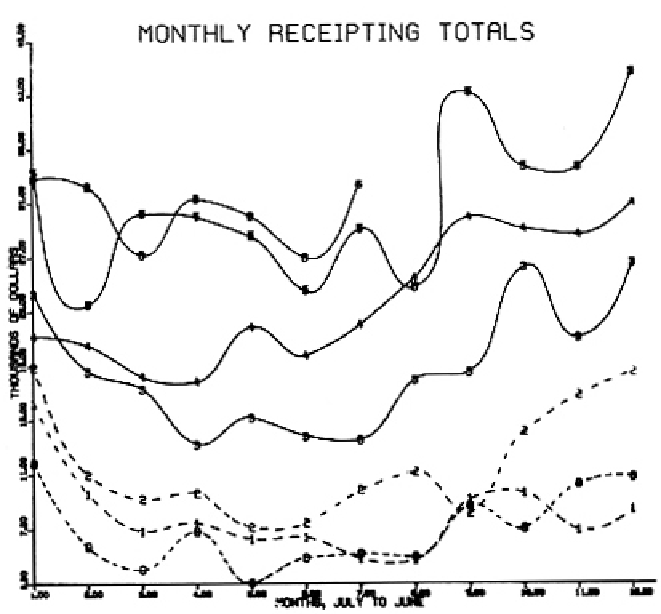
I have now taught this mini course four times, and during this time have formulated and class-tested various methods, programs, and forms of documentation, which have been continuously evolving to meet student needs.

It quickly became apparent that a user-oriented graphing system was necessary for the general interdisciplinary student to use -- a system that would depart from the complex CalComp-based subroutines, such as AXIS, LINE, SCALE, SYMBOL, and NUMBER. The latter routines can be used by programmers in making graphs via the computer, but the programming required to utilize the routines is far too difficult for interdisciplinary non-programmers.

THE CHART SYSTEM

In the spring of 1976, Professor Hertlein offered a graduate course in "Graphics Software Development", and with my vested interest in computerized graph-making, I joined the class and attacked the problem of making computer-assisted graphing more user-oriented.

BELOW: CURVED LINE GRAPH - The routine plots curved lines through successive (X,Y) coordinates, using solid or dashed lines and optional symbols.

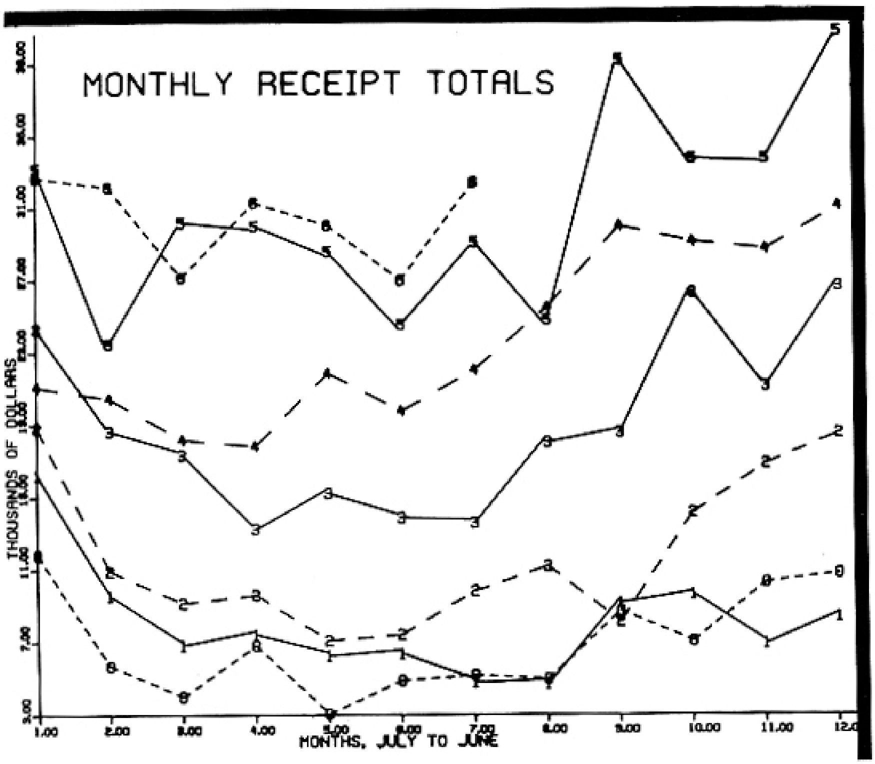


The class was divided into three team groups, each having a different task. Planning was accomplished by each team group, and programming tasks allocated to members. It was decided that the Graphing (CHART SYSTEM) would be standard in the basic form of each graph type, but flexible in the amount and type of data that could be graphed; in essence, to allow choice, but not a bewildering amount of it for new interdisciplinary students.

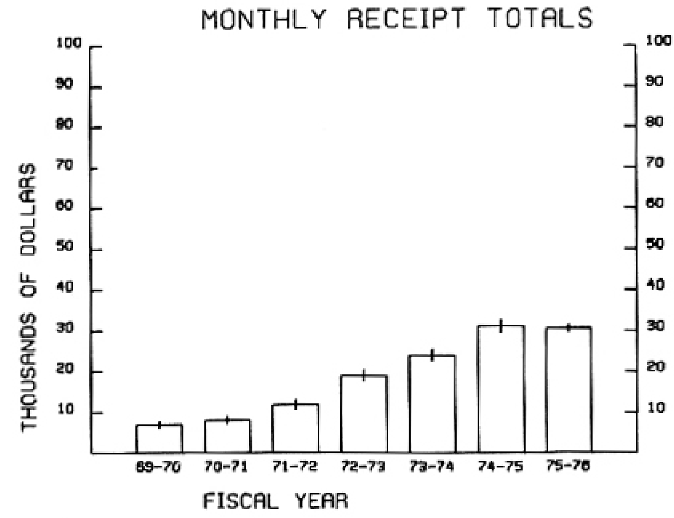
The intricacies of inputting data arrays, scaling them, outputting them on the printer, and calling the subroutines to graph the data, as well as how to label and document the graph are functions that the average user should not have to consider, especially in a one-unit mini course. Other difficulties encountered by the first two classes were: "running off the paper", getting more than one line on a graph, centering the graph on the paper, and debugging programs and data. We wished to eliminate as many of these problems as possible.

This goal was accomplished in the new graphing programs in time to class-test them on the third graphing class. The routines used were those developed by the Graphing Group mentioned earlier. Together we had managed to completely eliminate the need for the user to write a program in order to use the new CHART SYSTEM. Only a few control cards are now required to initiate the system. The user need only supply the data to be graphed in the proper formats.

BELOW: LINE GRAPH - This routine plots straight lines through successive (X,Y) coordinates using solid or dashed lines, and optional symbols.



BELOW: BAR GRAPH - Each bar may represent a single value or the mean and standard error for a number of values.



Presently included in the CHART SYSTEM are the following charts and graphs:

BAR GRAPH
COMPONENT BAR GRAPH
CURVED LINE GRAPH
FUNCTION GRAPH
GROUPED COMPONENT BAR GRAPH
HORIZONTAL BAR GRAPH
LINE GRAPH
PIE GRAPH
SCATTER DIAGRAM
SILHOUETTE CHART

All of these routines are programmed in FORTRAN IV, and make extense use of the support routines on the plotter library.

THE STUDENTS' RESPONSE

The students in the third and fourth graphing classes responded well to the new programs, and they had very few problems. The first two classes had considered the course material difficult; however, the last two groups found the new programs very easy to use. Keypunching, job control cards, and data formats presented few problems.

THE FUTURE

The CHART SYSTEM will be further refined and augmented before disseminating it to others. Our goal for computer-assisted graph-making will continue to be the promise: "No programming required."

NOTE: Because of space, not all the graphs discussed above are illustrated. The graphs shown are by the author.

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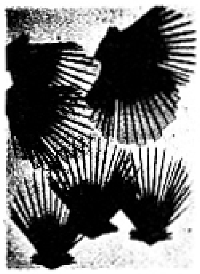

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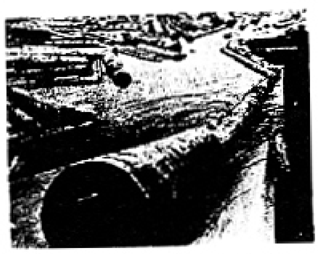

RAW INPUT FOR LUMBER MILL AND COMPUTER

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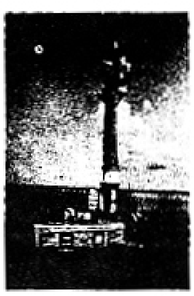

WEATHER–WATCHING BUOY

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IBM and the Maintenance of Monopoly Power

Dan L. McGurk, President, Computer Industry Assoc.
Competitive Restructuring of Monopoly Situations

Computers and Privacy

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The Assassination of President Kennedy: Computer Applications to the Photographic Evidence

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System Software Deciphering and "Cracking"

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Dr. Richard W. Hamming, Bell Telephone Labs, Inc.
The Computer and the Intellectual Frontier

Dr. Donald E. Knuth, Stanford University
Computer Science and Its Relation to Mathematics

Prof. Grace C. Hertlein, Calif. State University, Chico
Computer Art for the Artist

Prof. Joseph Raben, Queens College, N.Y.
Computers and the Future of Education

Wayne E. Shufelt, Sperry Rand Univac
Pictures of Mars by Mariner and by Computer

Lawrence M. Clark, Framingham, Mass.
Languages Among Computers, Machines, Animals and Men

Computer Programming

David W. Packer, Digital Equipment Corp.
Effective Program Design

L. H. Crandon, RCA, and P. G. Anderson, Newark College of Engineering
Computer Program Reliability

E. C. Berkeley and C. Otten, Berkeley Enterprises
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