Cartographic Symbology Panel

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Johnson: When I was asked to lead this panel discussion on cartographic symbology, I thought of the symbol set that we are currently using in the Soil Conservation Service (SCS) and believed that this was going to be a very narrow topic. Then I looked up the definition of cartographic symbol: "a letter, character, or other graphic device representing some feature, quality, or characteristic on a map or chart." This took the very narrow topic and made it very wide.

My area of interest is the production of base, soil, and topographic maps for SCS technicians' use. These maps include boundaries, roads, railroads, drainage, names, and, for soil maps, lines delineating soil boundaries. This week I have become aware of another type of map that uses symbology. Such a map might be classified as a statistical map, for example, maps that show population density, where certain crops are grown, production, slope, and many other items. I had asked someone to be on the panel to discuss this type of symbology but he was unable to attend so I will encourage you to comment on symbology for statistical mapping during the discussion period.

Hershey: As a mathematical physicist, I prepare equations which are published in laboratory reports. In order that my equations might be printed in an elegant format, I have had to develop my own typographic system. Specifications for the system have dictated that it should provide good quality, be completely versatile, and be fully automatic. The primary function of the system is printing mathematical reports, while a secondary function of the system is plotting cartographic material--not only maps but also graphs and diagrams. The system makes it possible to mix textual and graphical material on the same page.

The structure of my topographic system is controlled by limitations on the type of equipment which is available to me in my laboratory. We do not have automatic digitizers or character readers. We do have key punches, a computer, a mechanical plotter, and a cathode ray printer. Input to the computer is in the form of punched cards, and output from the cathode ray printer is microfilm.

One objective of the system is to provide a do-it-yourself capability to mathematicians and programers who would like to do some printing of their own. Interest in the system is indicated by the fact that one or more parts of it have been acquired by personnel in 64 agencies. The system is written in FORTRAN, making it available to an especially large number of users. It resides in permanent files which may be attached to the computer by anybody in the laboratory. For each application there is a different main program. The user must be competent to write his own main programs.

Time limitations preclude a description of the system in any detail. Figure 1 outlines the system. The punched card input can be prepared by hand or generated through programing on the computer. There are versions which will run on any one of three computers. Output is primarily for the SD4060 cathode ray printer, but there are converters which have made it possible to obtain output on four other devices.

Figure 2 indicates input to the system. The first kind of input is cartographic data. There are digitizations of the world, the United States, and the Potomac River. The digitization of the world has come to be known as World Data Bank 0. The digitization is a simulation of an irregular coastline by a polygon. Along any side of the polygon the coast line wiggles from one side to the other. A measure of the amount of wiggle is a measure of the accuracy of polygonization. The philosophy of my polygonization was that the simulation should conform uniformly to a specification of accuracy over the whole surface of the Earth. Specification of an accuracy of 15 min of arc led to a world data bank with 8,000 data. By contrast, World Data Bank I contains 56,000 data for coastlines on a Mercator projection. Thus the CIA world is 7 times as fine as my world; their accuracy should be on the order of 2 to 3 min of arc.

The conventional way to define the fineness of digitization is to state the scale of map for which it is appropriate. If one map were plotted on a postage stamp and another projected on the side of a barn, the scaling would be vastly different, yet the relative accuracy of the polygonization would be the same if both maps were derived from the same data bank. It is recommended that the accuracy of polygonization should be expressed in terms of the extent to which the coastlines actually deviate from whatever polygonization is used.

The second kind of input is calligraphic data. I have a complete occidental repertory and an oriental repertory with 600 Chinese characters. Each character in both repertories is simulated with polygons. The polygonization has required a considerable amount of artwork.

The third kind of input is control data, and there are three kinds of control data. A modal code sets the system into a plot mode or a print mode. Textual data tell the system what to print, and functional data tell the system how to print. There are only 48 characters in the FORTRAN character set, and these are used to evoke 1,377 symbols under control of the functional data. There is a mnemonic code to express the functional data.

In printing a report, there are two streams of control data. The continuous stream of text data is interrupted at the bottom of every page by the insertion of folio data. There is a basic input deck which has one slot to receive text data and another slot to receive folio data. The computation is under the control of a main program with subroutines.

THE FORTRAN TYPOGRAPHIC SYSTEM

INPUT

IBM Keypunch
Magnetic Tape

COMPUTER

IBM 360 UNIVAC 1108 CDC 6600

OUTPUT

S-D 4060

CalComp 718 FR-80 CalComp 1670

MS-6000

Figure 1

CARTOGRAPHIC DATA

World	United States	Potomac River
WORLDFILE		WORLDMAP
(Update)		(Binary)

CALLIGRAPHIC DATA

Occidental Repertory	Oriental Repertory
CHARFILE	CHARDATA
(Update)	(Binary)

CONTROL DATA

Text Data	Folio Data
TEXTO Program	FOLIO Program

MAIN PROGRAM

SUBROUTINES

SYMTYPO	BINTYPO
(Update)	(Binary)

Figure 2

Nonstandard input decks make possible an unlimited variety of combinations of textual material and graphical material.

The FORTRAN definition statements for the three principal subroutines are given in figure 3. The cartographic subroutine controls the plotting of charts; the textographic subroutine controls the printing of text; and the foliographic subroutine controls the printing of folio.

A perspective projection of the Earth after rotation through three Eulerian angles is illustrated in figure 4. The most spectacular demonstration of these globes is a movie in which the Earth is rotated about an equatorial diameter instead of the polar axis. A view of the Earth from the Moon is plotted in figure 5. This is the cartograpic equivalent of the shot of the Earth that CBS used in their news broadcasts.

Some of the symbols in the system are shown in figure 6; several are cartographic. My sales sample is shown in figure 7. The Russian word in the center column means complexity, and the Chinese word in the same column means calligraphy.

The first of a few exotics is illustrated in figure 8. A basic concept of the system is dividing a composition into patterns. Each pattern can be translated or rotated into position as a unit. Thus if we have a card deck which will generate Chlorophyll A, we have only to change one card to make it into a card deck for Chlorophyll B. The genetic code is illustrated in figure 9. It helps us to remember the fundamental structures in the double helix.

Components of electronic circuits are illustrated in figure 10. Each pattern in the set of components is represented by a card deck. By duplicating the card decks and inserting additional cards, the components are connected with lines to make a complete circuit diagram.

The power of the system to crank out equations is demonstated by figure 11. I counted the number of equations until I reached 1,000, and then I gave up. The first bit of printing with the system is shown in figure 12. The section lines of a ship are illustrated in figure 13. This is a mixture of textual material and cartographic material in a single pattern, all derived from a single input deck.

LeBlanc: I will address cartographic symbology in the context of an automated drafting system in operation in the Government of Ontario. What follows is a description of the system and an analysis--by no means thorough--of a few deficiencies of the general symbolization capability, applied to cartography. The system is a customized drafting system which may possibly serve a purpose other than originally intended. The issue, then, is one that some cartogaphers may be familiar with; namely, second generation use of a technology that was developed to produce graphics which are now only a subset of a broader graphic requirement.

The Gerber 1232 Automated Drafting System was developed for photogrammetric production at large scale, principally from 1:500 to 1:2,500, of monochrome engineering plans for highway planning, design, and con-

FORTRAN TYPOGRAPHIC SYSTEM

```
      SUBROUTINE CTGPHC (LW, KF, CF, CA, NI, NO, GNLTRN)
******************************************************************
      FORTRAN CARTOGRAPHIC SUBROUTINE
******************************************************************
      LW = WIDTH OF LINE (FORTRAN INTEGER)
      KF = FORMAT ARRAY (SYMBOLIC ADDRESS)
      CF = FIELD ARRAY (SYMBOLIC ADDRESS)
      CA = AREA ARRAY (SYMBOLIC ADDRESS)
      NI = INPUT TAPE NUMBER (FORTRAN INTEGER)
      NO = OUTPUT TAPE NUMBER (FORTRAN INTEGER)
      EXTERNAL GNLTRN (AQ, FP)
      AQ = ARGUMENT ARRAY (SYMBOLIC ADDRESS)
      FP = FUNCTION ARRAY (SYMBOLIC ADDRESS)


      SUBROUTINE TXGPHC (NL, NI, NO, AI, AD, NR)
******************************************************************
      FORTRAN TEXTOGRAPHIC SUBROUTINE
******************************************************************
      NL = LINE NUMBER CONTROL (FORTRAN INTEGER)
      NI = INPUT TAPE NUMBER (FORTRAN INTEGER)
      NO = OUTPUT TAPE NUMBER (FORTRAN INTEGER)
      AI = INDEX ARRAY (SYMBOLIC ADDRESS)
      AD = DATUM ARRAY (SYMBOLIC ADDRESS)
      NR = RETURN NUMBER CONTROL (FORTRAN INTEGER)


      SUBROUTINE FLGPHC (NL, NI, NO, AI, AD, NR)
******************************************************************
      FORTRAN FOLIOGRAPHIC SUBROUTINE
******************************************************************
      NL = LINE NUMBER CONTROL (FORTRAN INTEGER)
      NI = INPUT TAPE NUMBER (FORTRAN INTEGER)
      NO = OUTPUT TAPE NUMBER (FORTRAN INTEGER)
      AI = INDEX ARRAY (SYMBOLIC ADDRESS)
      AD = DATUM ARRAY (SYMBOLIC ADDRESS)
      NR = RETURN NUMBER CONTROL (FORTRAN INTEGER)
```

Figure 3

Figure 4

FOURTH EARTHRISE DURING APOLLO 8 MISSION

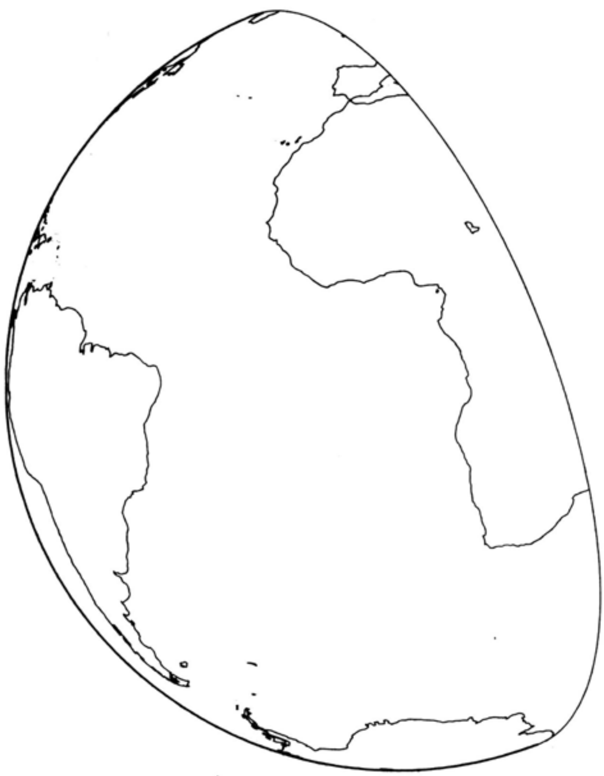


Figure 5

SYMBOLS

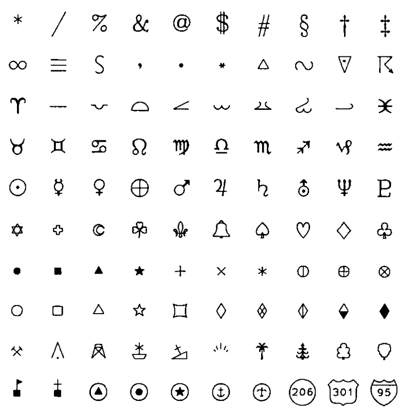


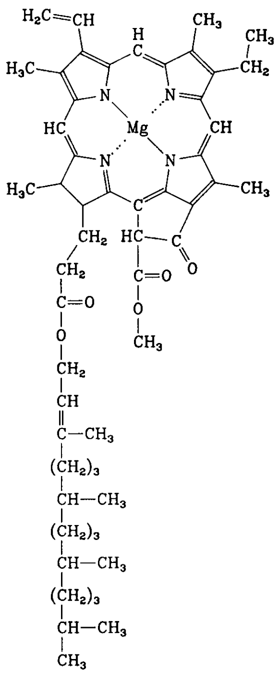
Figure 6

Invitation	COMMUNICATION	*Publication*
ECONOMY	*VERSATILITY*	**Quality**
CARTOGRAPHY	Standardization	TYPOGRAPHY
Γραμμα	Συμβολον	Αριϑμος
Графика	СЛОЖНОСТЬ	Фонетика
Rotation	EXTENSION	ROTATION
	CONDENSATION	
Syllabary	ΛΕΞΙΚΟΝ	Alphabet
Art	書道	**Music**
Meteorology	**Wiſſenſchaft**	**Astronomy**
CHEMISTRY	*Electronics*	MATHEMATICS
Analysis	COMPUTATION	*Program*

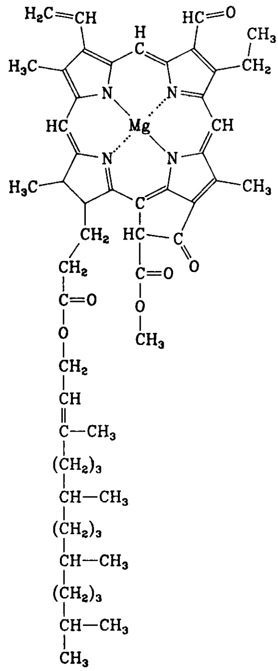
Figure 7

STRUCTURES

CHLOROPHYLL A



CHLOROPHYLL B



ADENOSINE TRIPHOSPHATE

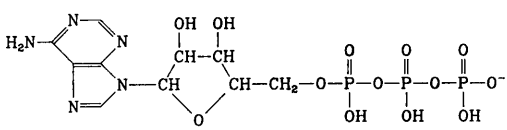


Figure 8

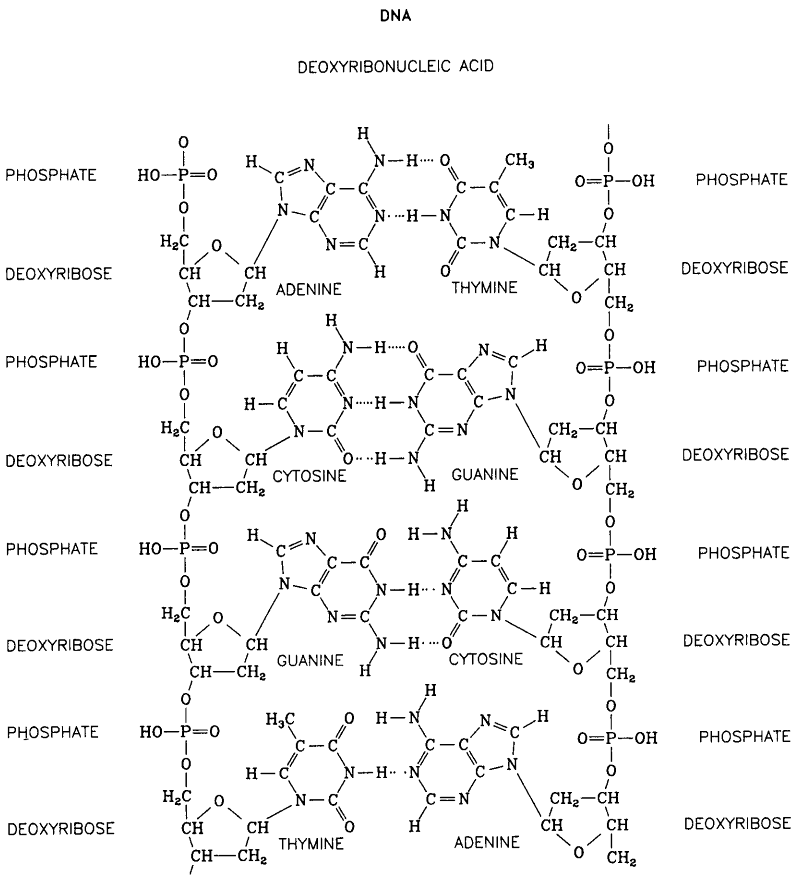

DNA
DEOXYRIBONUCLEIC ACID
PHOSPHATE
DEOXYRIBOSE
PHOSPHATE
DEOXYRIBOSE
PHOSPHATE
DEOXYRIBOSE
PHOSPHATE
DEOXYRIBOSE
ADENINE
THYMINE
CYTOSINE
GUANINE
GUANINE
CYTOSINE
THYMINE
ADENINE
PHOSPHATE
DEOXYRIBOSE
PHOSPHATE
DEOXYRIBOSE
PHOSPHATE
DEOXYRIBOSE
PHOSPHATE
DEOXYRIBOSE

Figure 9

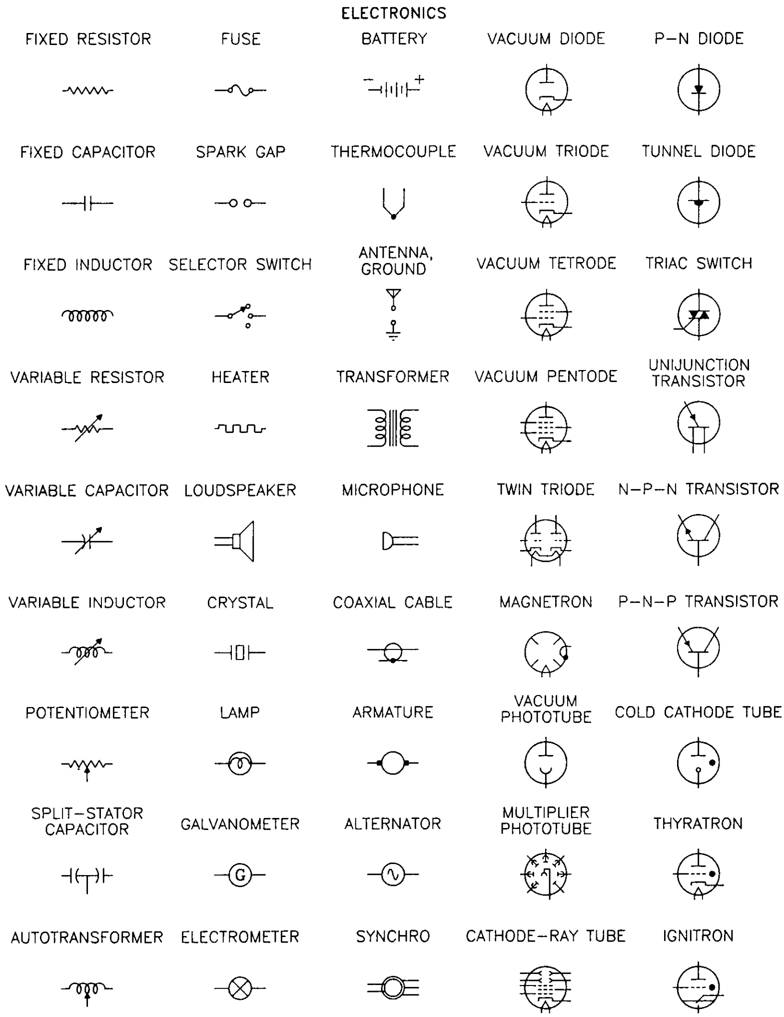

ELECTRONICS
FIXED RESISTOR
FUSE
BATTERY
VACUUM DIODE
P–N DIODE
FIXED CAPACITOR
SPARK GAP
THERMOCOUPLE
VACUUM TRIODE
TUNNEL DIODE
FIXED INDUCTOR
SELECTOR SWITCH
ANTENNA, GROUND
VACUUM TETRODE
TRIAC SWITCH
VARIABLE RESISTOR
HEATER
TRANSFORMER
VACUUM PENTODE
UNIJUNCTION TRANSISTOR
VARIABLE CAPACITOR
LOUDSPEAKER
MICROPHONE
TWIN TRIODE
N–P–N TRANSISTOR
VARIABLE INDUCTOR
CRYSTAL
COAXIAL CABLE
MAGNETRON
P–N–P TRANSISTOR
POTENTIOMETER
LAMP
ARMATURE
VACUUM PHOTOTUBE
COLD CATHODE TUBE
SPLIT–STATOR CAPACITOR
GALVANOMETER
ALTERNATOR
MULTIPLIER PHOTOTUBE
THYRATRON
AUTOTRANSFORMER
ELECTROMETER
SYNCHRO
CATHODE–RAY TUBE
IGNITRON

Figure 10

TABLE I

ELLIPSOIDAL INTEGRALS

$$X = \int_{\xi}^{\infty} \frac{d\theta}{\sqrt{4(a^2+\theta)(b^2+\theta)(c^2+\theta)}} = \frac{1}{(a^2-c^2)^{\frac{1}{2}}} \int_0^{\phi} \frac{d\varphi}{\sqrt{1-k^2\sin^2\varphi}} \quad (1)$$

$$A = \int_{\xi}^{\infty} \frac{d\theta}{(a^2+\theta)\sqrt{4(a^2+\theta)(b^2+\theta)(c^2+\theta)}} = \frac{1}{(a^2-c^2)^{\frac{3}{2}}} \int_0^{\phi} \frac{\sin^2\varphi\, d\varphi}{\sqrt{1-k^2\sin^2\varphi}} \quad (2)$$

$$B = \int_{\xi}^{\infty} \frac{d\theta}{(b^2+\theta)\sqrt{4(a^2+\theta)(b^2+\theta)(c^2+\theta)}} = \frac{1}{(a^2-c^2)^{\frac{3}{2}}} \int_0^{\phi} \frac{\sin^2\varphi\, d\varphi}{(1-k^2\sin^2\varphi)^{\frac{3}{2}}} \quad (3)$$

$$C = \int_{\xi}^{\infty} \frac{d\theta}{(c^2+\theta)\sqrt{4(a^2+\theta)(b^2+\theta)(c^2+\theta)}} = \frac{1}{(a^2-c^2)^{\frac{3}{2}}} \int_0^{\phi} \frac{\sin^2\varphi\, d\varphi}{\cos^2\varphi\sqrt{1-k^2\sin^2\varphi}} \quad (4)$$

$$L = \int_{\xi}^{\infty} \frac{d\theta}{(b^2+\theta)(c^2+\theta)\sqrt{4(a^2+\theta)(b^2+\theta)(c^2+\theta)}} = \frac{1}{(a^2-c^2)^{\frac{5}{2}}} \int_0^{\phi} \frac{\sin^4\varphi\, d\varphi}{\cos^2\varphi(1-k^2\sin^2\varphi)^{\frac{3}{2}}} \quad (5)$$

$$M = \int_{\xi}^{\infty} \frac{d\theta}{(c^2+\theta)(a^2+\theta)\sqrt{4(a^2+\theta)(b^2+\theta)(c^2+\theta)}} = \frac{1}{(a^2-c^2)^{\frac{5}{2}}} \int_0^{\phi} \frac{\sin^4\varphi\, d\varphi}{\cos^2\varphi\sqrt{1-k^2\sin^2\varphi}} \quad (6)$$

$$N = \int_{\xi}^{\infty} \frac{d\theta}{(a^2+\theta)(b^2+\theta)\sqrt{4(a^2+\theta)(b^2+\theta)(c^2+\theta)}} = \frac{1}{(a^2-c^2)^{\frac{5}{2}}} \int_0^{\phi} \frac{\sin^4\varphi\, d\varphi}{(1-k^2\sin^2\varphi)^{\frac{3}{2}}} \quad (7)$$

$$P = \int_{\xi}^{\infty} \frac{d\theta}{(\theta-p)^2\sqrt{4(a^2+\theta)(b^2+\theta)(c^2+\theta)}} = \frac{1}{(a^2-c^2)^{\frac{5}{2}}} \int_0^{\phi} \frac{\sin^4\varphi\, d\varphi}{(1-\alpha^2\sin^2\varphi)^2\sqrt{1-k^2\sin^2\varphi}} \quad (8)$$

$$Q = \int_{\xi}^{\infty} \frac{d\theta}{(\theta-q)^2\sqrt{4(a^2+\theta)(b^2+\theta)(c^2+\theta)}} = \frac{1}{(a^2-c^2)^{\frac{5}{2}}} \int_0^{\phi} \frac{\sin^4\varphi\, d\varphi}{(1-\alpha^2\sin^2\varphi)^2\sqrt{1-k^2\sin^2\varphi}} \quad (9)$$

Figure 11

RELATIVITY

That the velocity of light is independent of the motion of the observer was indicated first by the experiments of Michelson and Morley The constancy of the velocity of light is only one manifestation of the principle of relativity, which may be stated in the following way

It is not possible by any physical experiment to determine an absolute motion through space

An implication of the principle of relativity is that all scalars, vectors, and tensors which represent physical quantities are invariant with respect to the speed of the reference frame to which they are referred

Let a spherical light wave emanate from an origin of coordinates at zero time and expand with the speed of light The equation of the light wave is

$$x^2 + y^2 + z^2 - c^2t^2 = 0 \tag{1}$$

where x, y, z, t are the Cartesian coordinates and the time of a point in the light wave and c is the speed of light. Invariance of the scalar function in Equation (1) implies that a position vector $\mathbf{r}$ with coordinates

$$(x, y, z, ict) \tag{2}$$

is invariant in a four-dimensional space whose metric is given by the equation

$$(dl)^2 = (dx)^2 + (dy)^2 + (dz)^2 - c^2(dt)^2 \tag{3}$$

The vector $\mathbf{r}$ may be differentiated with respect to the metric l to obtain new invariants which satisfy the identity

$$\frac{d}{dl}\left(\frac{d\mathbf{r}}{dl}\,\frac{d\mathbf{r}}{dl}\right) = 2\,\frac{d\mathbf{r}}{dl}\,\frac{d^2\mathbf{r}}{dl^2} = 0 \tag{4}$$

Associated with a particle is a rest mass m_0 which is a physical quantity and is invariant by the principle of relativity Associated with the particle is a momentum vector $\mathbf{p}$ which may be defined by the equation

$$\mathbf{p} = im_0c\,\frac{d\mathbf{r}}{dl} \tag{5}$$

Application of the Identity (4) to the momentum vector $\mathbf{p}$ leads to Einstein's law of the equivalence of mass and energy. The prediction of the equivalence of mass and energy is one theory which has been confirmed in the most spectacular way by practical applications It gives the source of energy for nuclear bombs

Figure 12

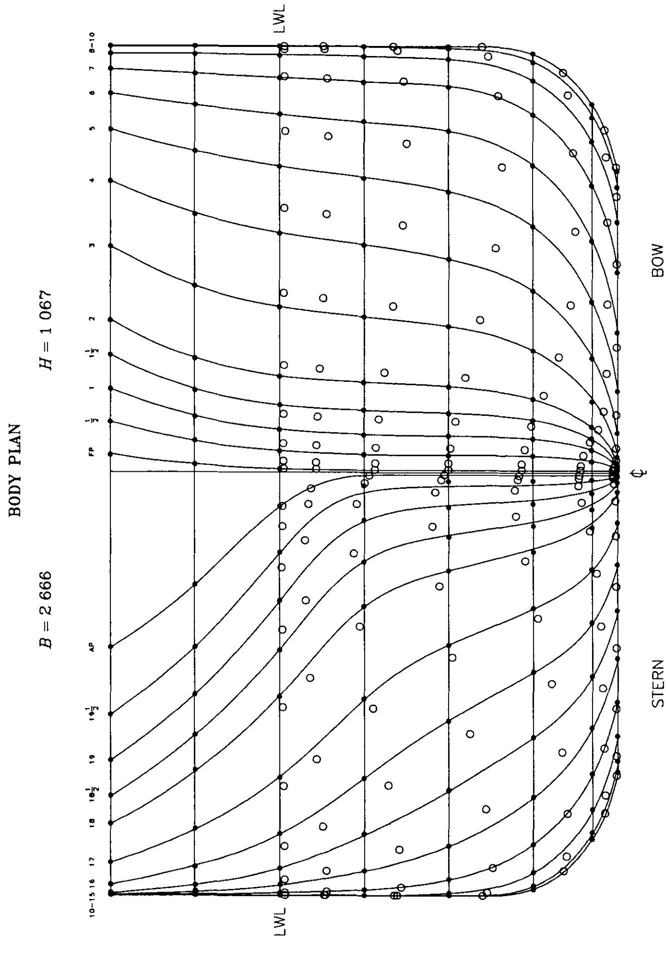


Figure 1 Section Lines of Series 60, Block 0 60 Ship Model •, Tabular Offsets from NSRDC Report No 1712, −, Orthonormal Polynomial Representation, o, Coordinates for Chebyshev Spacing along Section Line and along Longitudinal Axis

struction in the Ontario Ministry of Transportation and Communications. Figure 1 shows the hardware configuration. Three-dimensional data are obtained off-line (on 7-track magnetic tape) from four Zeiss D2 planimats interfaced to Wang 2300 and GRADICON digitizers; the two-dimensional digitizing units (Coordinatograph, Instronics) are not included in the diagram. The central processer is a Hewlett-Packard 2116 with the peripherals shown. The plotter is a Gerber 32 flatbed.

Figure 2 is a portion of a standard plot at a scale of 1:480, now being converted through the metrication program to 1:500. The range of symbolization at this scale is demonstrated. The less obvious cloud-like symbols are deciduous trees which are plotted using a center-point-radius software routine. The simplicity of the overall product is rather evident.

Figure 3 is a slightly generalized plot at a scale of 1:2,400. Most of the symbols that are presently used are revealed on this particular plot. Figure 4 is a portion of a 1:10,000-scale plan; this is not the normal output scale but is shown here for comparison. It is possible to generalize data to an even smaller scale.

Figure 5 is an experimental sheet which was produced to demonstrate medium-scale data handling capability and a multicolor product. It is simply an attempt to duplicate a topographic sheet (minus most typography) of the Peterborough area of Ontario at 1:25,000 scale. The photographs were taken, digitized, and plotted for this particular scale. Note that most of the symbology, such as point symbols, is extremely generalized; for example, buildings are shown as dots rather than as rectangles which are used at larger scales.

My Cartography Section has been offered the use of this system as technical support in the production of 1:250,000-scale multicolor transportation maps (fig. 6). There are certain symbolization problems inherent in this new production requirement. First, there is the dichotomy of symbol character caused by the need for generalization: those symbols which are presently plotted according to a definition in a symbol library versus those symbols which are flashed. If the same data that are used for large-scale plan plots were used for smaller scale maps (e.g., the 1:250,000-scale transportation maps), a problem arises when a software-defined symbol is perhaps better plotted at a smaller scale using a flashed symbol. At what scale and in what manner the symbol definitions change have not been established for all features.

The image font of the optical exposure head of the Gerber 32 has a capacity of 24 images, some of which are presently used for linework and others for relevant point symbols. Much symbology is software-generated, including lettering. At a smaller scale, however, a greater number and variety of line, point, and alphanumeric symbols are needed; most would be simple and lend themselves to being flashed, but the 24-image capacity would be vastly exceeded. Recent research and development have perhaps provided an answer to the need for various type faces, but potential incompatibilities are not known. Another liability is the nonrotation of the photo-head, which further limits the possibilities of orienting the symbols. Also, there is no interactive display/edit capability for error and interference detection; the latter is much more of a problem with small-scale maps than with plans.

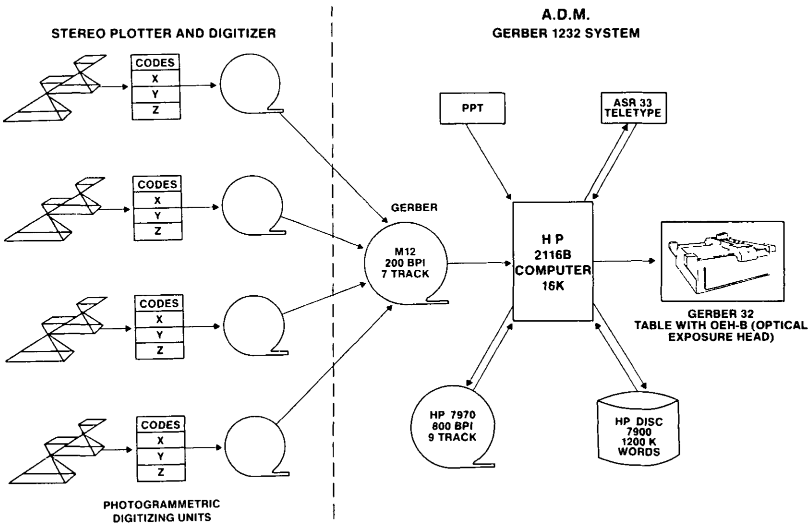


Figure 1.--Hardware configuration for Automated Drafting System (After MacLeod and Turner, 1971).

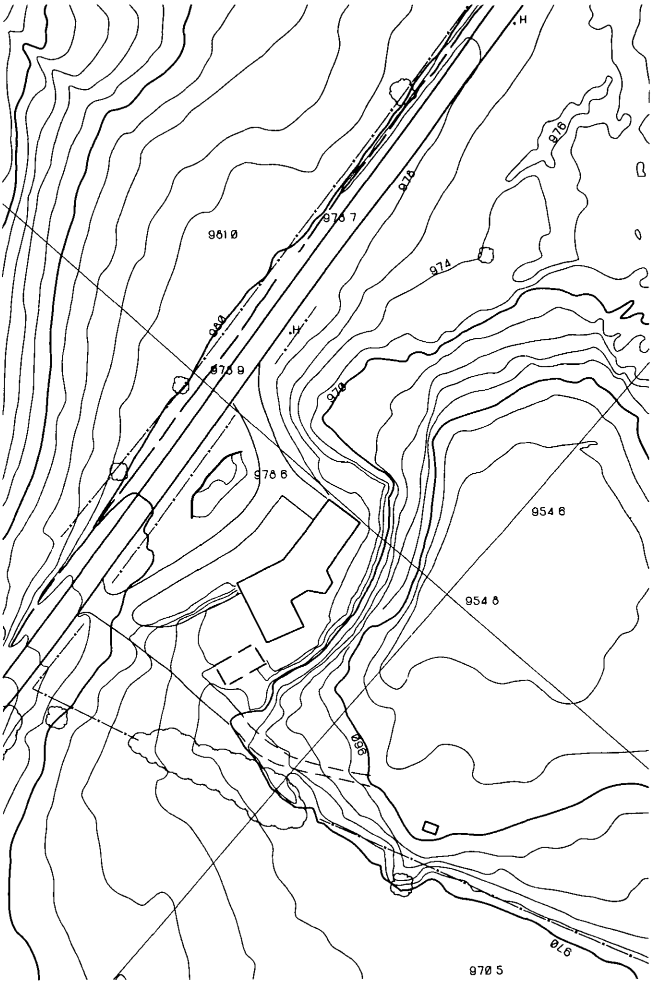


Figure 2.--Portion of an ADM plot at a scale of
1:480 with a 2-ft contour interval.

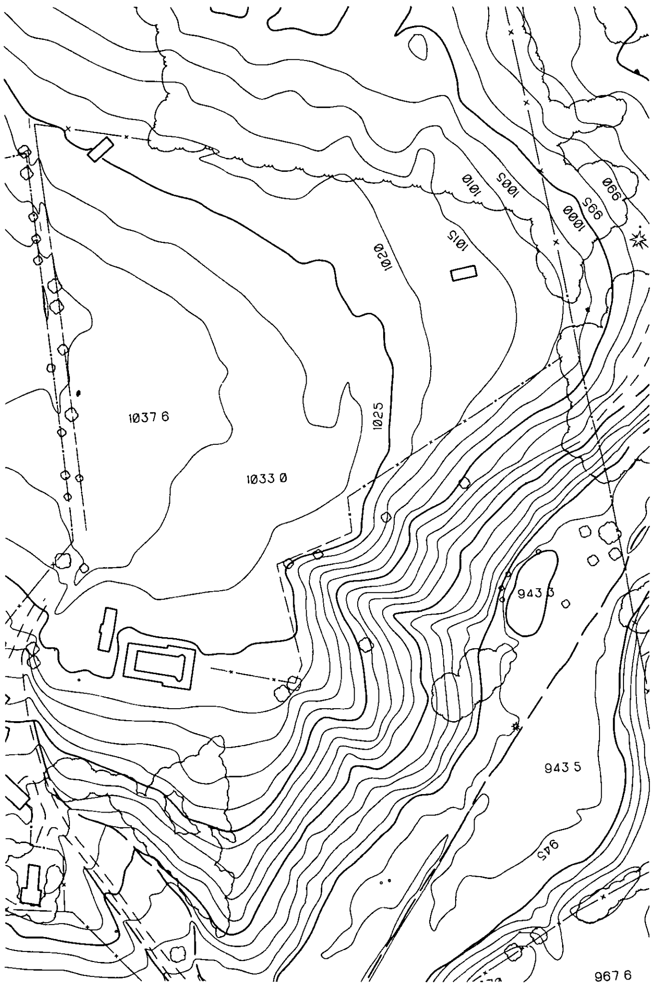


Figure 3.--Portion of an ADM plot at a scale of 1:2400 with a 5-ft contour interval.

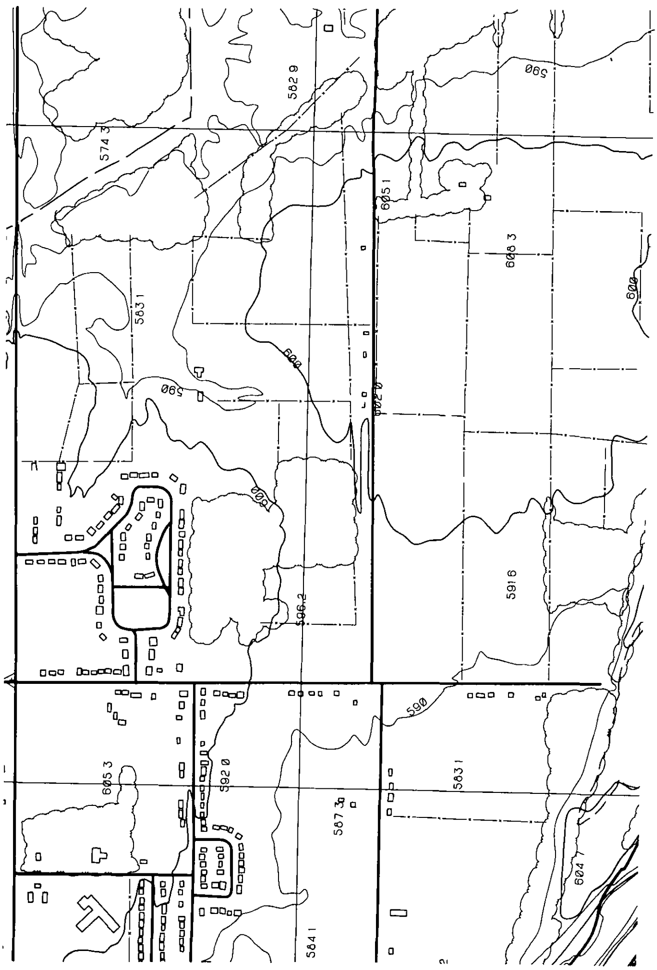


Figure 4.--Derived plot at 1:10,000 scale. Note that each building remains plottable as a unique feature.

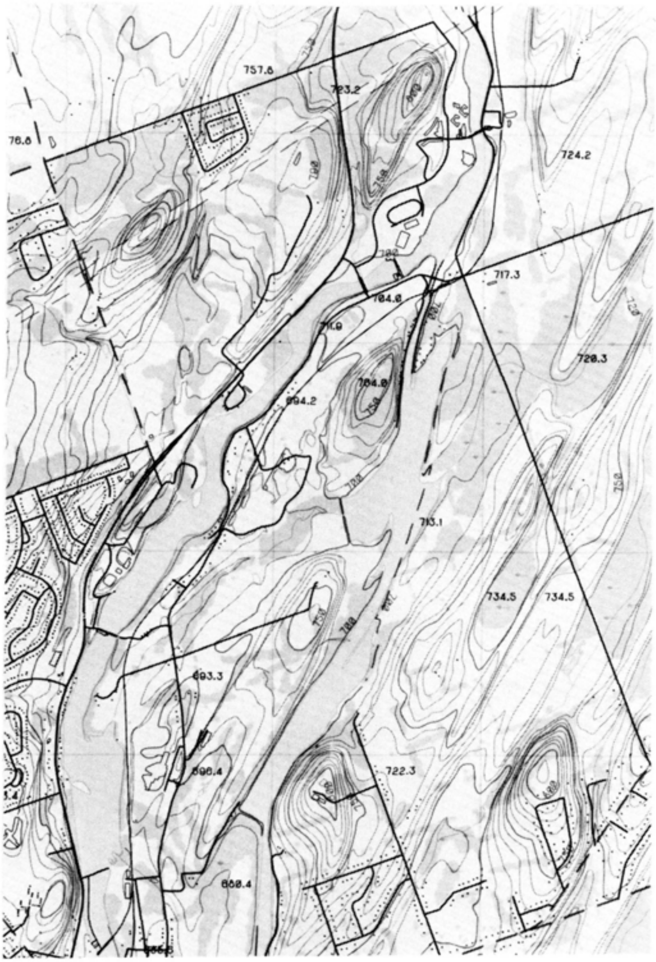


Figure 5.--Small section of a 1971 four-color experimental map, duplicating the area covered by a National Topographic System 1:25,000 sheet. Pre-punched matte autopositives were sequenced manually on the plotting table; peelcoats were etched subsequently.

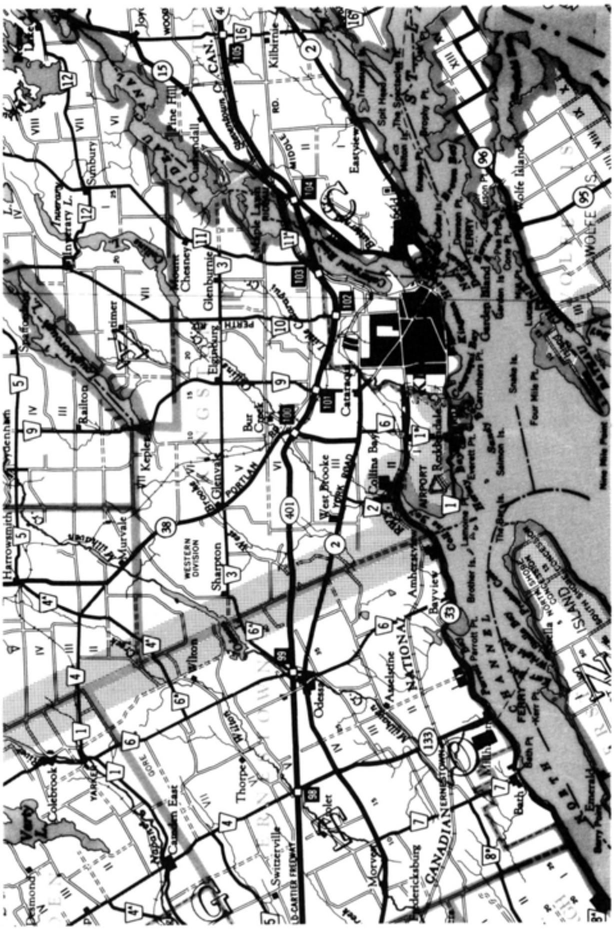


Figure 6.--Section of a conventional four-color planimetric transportation (road) map at 1:250,000 scale.

A second observation concerns the digitizing and coding procedure. The basic record currently recognized by most software is a product of: a code that identifies the feature; a subcode that is simply a sequential numbering of features within a code, which is used to turn on/off the optical exposure head as it moves from one feature to the next; an accuracy code which reflects the scale of original digitizing and is ultimately useful in generalization subroutines; and the x, y, and z coordinates.

CODE + SUBCODE + ACCURACY CODE + COORDINATES
+ OPTIONAL ANNOTATION = RECORD for one point.

The structure is a general-purpose one and should accommodate extended usage with limited difficulty.

A third consideration is that there is not a demand for symbology in engineering plans, so much as extensive use of area tints. To mechanically plot the area tints needed for transportation or other maps, it would be necessary to introduce some sort of systematic and efficient "beaming" algorithm whereby an area is beamed and a peripheral mask is used to limit the "scalloped" edge. This capability is not available now but is certainly obtainable.

The concept of image repeatability (or table registry) is particularly important to the color separation of 1:250,000-scale maps. Adjacent areas plotted on separate pieces of film must join, so that the repeatability of the line separating them is crucial. Of course, the Gerber plotter possesses good repeatability.

There is a commitment inherent in the present system to duplicate the manual method. This system philosophy has led to a particular hardware configuration, data handling capability, and software which reinforce the use of the system as technical support and not as an alternate production system which could create, perhaps, unique or better graphics.

Johnson: The Soil Conservation Service has a digitizer, computer-probe software, and a Gerber drafting machine. I have four different character sets which fall somewhere between the symbology described by Hershey and LeBlanc. Our publication, "Symbology for Mapping," shows all the symbols we use for boundaries, hydrology, transportation, utilities, highways, and soils.

(Unidentified speaker): Mr. LeBlanc, I noticed two things in the last slide (fig. 6). The first one you commented on is that the houses are circular dots; the second is that the streets appear to be all single lines. I won't say that it is conventional to show double-line streets and square houses, but I wonder if you have received any adverse commentary about that particular choice of symbols and, if so, are any of them in you opinion really valid?

LeBlanc: Yes, and yes. The house symbol is round simply because the beam is round; for the time being there is no capability for squaring off the beam. That is one of the problems with using a beam to flash across an area symbol; the beam surpasses the limits of that area and you have to use some manual knockout procedure to limit it. At that scale, which by the way was experimental, there really wasn't much point in trying to get a particular type of sophistication. Double-line streets, which are relevant to the color products that I produce, are a problem. At the scale of engineering plans, both sides of a road are digitized separately and plotted that way. For smaller scale mapping, digitizing down the center or generalizing from two sides (i. e., calulating from a center point and then plotting parallel lines) are being investigated. One possible resolution is to use a beam-splitting mirror to create a double line.

Forstall (U.S. Forest Service): I have been doing a little bit of work programing this sort of symbolization. I would be delighted to talk to you, sir, and to anybody who is interested in exchanging further ideas on the subject.