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GRAPHICAL PLOTTING OUTPUT ON A LINE PRINTER USING HIGH-DENSITY PLOTTING SYMBOLS *

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In using a digital computer for scientific calculations, data reduction and analysis, or on-line data collection it is desirable with surprising frequency to have some form of graphical representation of the numerical results. This problem is often solved by either using the standard characters of a line printer to produce graphical plotted output [1] or by employing some special plotting device such as an incremental plotter to produce similar output.

Both of these solutions have certain disadvantages. In particular, the plotting resolution on a standard line printer is very poor: 6 characters per inch in the vertical direction and 10 characters per inch in the horizontal direction. This results in plots which, in many cases, are too crude to give more than a rough qualitative indication of the numerical data plotted. However, the line printer output is very rapidly generated, the plots can be produced as an integral part of the numerical output, and line-printer plotting routines are simple, generally requiring only a few hundred words of memory.

On the other hand, special plotting devices, while offering excellent plotting resolution on the order of 100 characters per inch, require that an additional output device be added to the system, increasing capital, operating and maintenance costs. Further, incremental plotters are slow and usually require very large handling programs because of the necessity of producing letters and characters by software, thus making less memory available for other purposes and requiring fairly large efforts in software development. To the user there is the additional disadvantage that the graphical output and the numerical output are physically separated, often not available at the same time, cannot be easily stored together, and must be collated before comparisons can be made.

In the design of the SDS 930 on-line data collection system in use at the University of Washington Nuclear Physics Laboratory we have provided an intermediate solution to the problem of graphical output which lies somewhere between the two discussed above, combining the speed and simplicity of line printer plotting with improved plotting resolution on the order of 20 characters per inch. This has been accomplished by converting the 16 "lost" characters which are present on most line printers to high density plotting characters.

The 16 characters mentioned above are those character set present on most line printers which are *not* a part of the 48 FORTRAN characters: {A through Z}, {0 through 9}, {blank + – * / = ( ) . , $} and {'} used in many FORTRAN dialects. The remaining 16 characters are "lost" in the sense that they are not standardized, are not available in FORTRAN without employing trickery, and are infrequently used or even seen except when the line printer is being tested.

We have used these 16 "lost" character positions, along with the standard minus sign, to form a set of 17 high-density plotting characters for the generation of good-resolution graphical output on the line printer. These characters, in conjunction with any one of several FORTRAN plotting subprograms, have proved very effective in years of use in generating large volumes of good-resolution graphical output. Two kinds of plotting symbols, X's and ○'s, and vertical and horizontal grid lines may be plotted with a resolution of 18/inch vertically and 20/inch horizontally. This resolution, which is comparable with 20/inch graph paper, has been found to be quite adequate for most purposes. While such computer-generated plots are usually not suitable for publication directly, line drawings

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for publication can be traced directly from computer output.

The high density plotting character set is illustrated in fig. 1. The outline rectangles shown are not a part of the plotting character but illustrate the "character-rectangle", i.e., the space $\frac{1}{6}$ inch by $\frac{1}{10}$ inch in area, occupied by a standard line printer letter, number or symbol. Each of the available plotting symbols, X's and O's, has a set of six special characters associated with it. The set for the symbol X, for instance, consists of six characters each with a small X in a different place in the character rectangle; in particular, in the upper left, upper right, middle left, middle right, lower left, and lower right of the character rectangle.

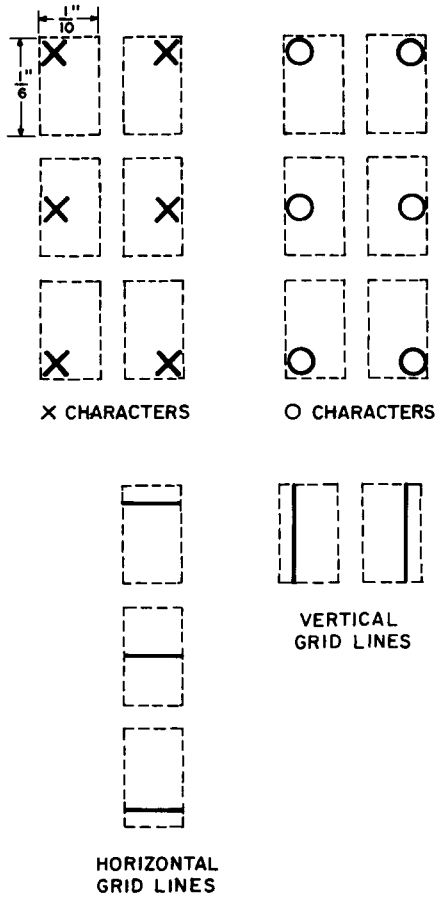

Fig. 1. The complete set of 17 high-density plotting characters. Indicated rectangles are not a part of the characters, but are included to show the placement of the plotting symbol within the available character area.

A similar set of O-characters is provided.

It was decided that vertical and horizontal grid lines should be provided with the same position resolution as the plotting symbols and that the grid lines should *intersect* the plotting characters (rather than falling in the gaps between characters). The grid-line characters thus required consist of a left- and right-displaced vertical bar and an upward- and downward-displaced horizontal bar, along with a middle horizontal bar, i.e., the minus sign.

Fig. 2 shows some typical graphical output generated with the line printer * of the on-line computer system of the University of Washington Nuclear Physics Laboratory, which is equipped with high-density plotting characters of the type described above. One of the examples in fig. 2 illustrates a case where numerical and graphical output are combined, a decided advantage in certain data analysis situations.

To employ the plotting characters as described, the line printer used must be capable of suppressed spacing so that a given line can be overprinted one or more times. This requirement is not a serious limitation, since almost all commercial line printers are provided with this capability, and it can usually be employed in FORTRAN by putting some character such as a + or a – in the first column of the print line. However, the necessity of overprinting does slow down the line printer output. The line printer speed could be reduced by a factor of 17 if all of 17 plotting characters had to be overprinted in the same character space on every line. In practice, this extreme never occurs, and a more typical speed reduction factor is between 2 and 3, depending on the distribution of the plotted data on the page. Special techniques for suppressing the plotting of a few characters to speed up the plotting can result in plotting at full line-printer speed.

A detailed description of the plotting programs used with these high-density characters is beyond the scope of this paper. However, a few words are appropriate concerning the algorithms employed in writing such a program in FORTRAN. First of all, the symbols must be defined. This may prove difficult since these characters are, by definition, not a part of the FORTRAN character set. The technique which we have employed to provide the necessary definitions is to deduce a set of integer constants which, when

* Manufactured by Data Products, Inc.

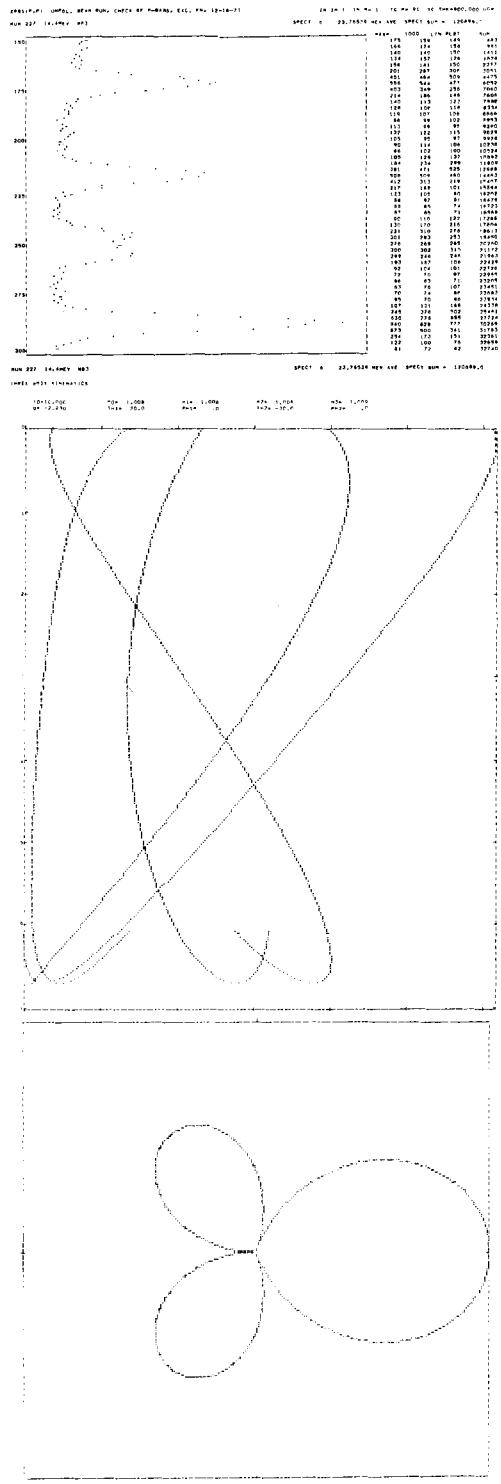

Fig. 2. Examples of graphical output (a). A pulse height spectrum with numbers of counts to the right (b). Plot of three-body reaction kinematics (c). Polar plot of the reduced rotation matrix element $d^{3/2}_{1/2\ 1/2}(\theta)$.

printed in an Al format, generate the set of plotting characters on the line printer. This requires only knowing the correct bit pattern and converting it to the corresponding decimal integer.

The algorithm for the generation of a print line is also worth mentioning. Initially, a one-dimensional array representing the line to be printed is blanked, i.e., blank characters are inserted in all positions in the array. The appropriate grid lines are then inserted, and then all points to be plotted on the line are inserted, with the appropriate plotting character. Before each substitution into the array is made, a test is made to insure that the position presently contains a blank character. If not, the plotting character and its location on the line are stored in an overflow table. When all points to be plotted in the present line are processed in this way, the line is printed in Al format and blanked. Then the overflow table is examined for outstanding entries and these are deleted from the table as they are entered in the plot line array. When a plot line position is found to be non-blank the entry is left in the overflow table. In this way, the overflow table is cleared out and one or more overprinted lines are generated. The algorithm insures that no lines are overprinted unless it is absolutely necessary, and the line printer runs as fast as possible.

The cost of obtaining a set of high-density plotting characters for a line printer is something of a variable. If they were an optional standard feature of a manufacturer, there would be no incremental cost, but no

Table 1
Character requirements for high density plotting.

Vertical resolution (per inch)	Horizontal resolution (per inch)	Characters per symbol	Characters for grid lines
6	10 (standard)	1 a)	2 c)
12	10	2	3
18	10	3	4 c)
12	20	4	4
18	20	6	5 c)
24	20	8	6
18	30	9 b)	6 c)
24	30	12 b)	7
30	30	15 b)	8 c)

a) Any standard character may be used for plotting.
b) The lower-middle circle or point character may also be used for the period or decimal point (.).
c) The middle horizontal grid line may also be used for the minus sign (−).

manufacturer presently offers this option. If they are a part of a new system, as was the case in the system described above, the cost is fairly modest, since a printer with a modified print drum or chain is initially ordered; in our case, the incremental cost was about $500. On the other hand, purchasing a new drum or chain without obtaining a credit on the old one can be considerably more expensive, though probably much cheaper than the cost of an incremental plotter.

It should be mentioned in closing that the plotting scheme described above can be expanded or contracted, depending on the requirements of plotting resolution and the availability of characters to devote to plotting purposes. Table 1 gives the number of plotting characters required as a function of plotting resolution, for resolutions up to 30/inch vertically and horizontally. If several symbols are desired, *each* must be provided with the number of character positions indicated.

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Reference

[1] C.F. Moore, Computer Phys. Commun. 2 (1971) 55.