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A Data-Trend Log and Bar Graph Display for Physiological Monitoring

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The task of presenting data derived from measurements of physiological variables on a patient in an intensive care unit to a physician in a form that will best serve him in making decisions about the patient, is a challenging one. The physician would like to see the most recent data in most detail and at the same time relate these measurements to data obtained earlier in time. To accomplish this, a bar graph display is used which represents the variable values as a function of time expressed as $Ln_2((t_p - t_m)/t_i)$, where Ln_2 is the interger part of the logorithm to the base 2, t_p is the present time, t_m is the time of measurement, and t_i is the time between measurements (Fig. 1).

Since most variables are not measured continuously in an intensive care ward, time is plotted discontinuously in the form of a series of bar graphs, one for each integral value of the independent variable, $Ln_2((t_p - t_m)/t_i)$. The height of the nth bar represents the mean value of $(n/2)$ measurements and no measurement is represented in more than one bar. For example, only the most recent measurement is represented by the left most bar, the second bar is the average of the two measurements preceding this one, the third bar is an average of the four preceding these two, etc. (see Table 1). The width of each bar is plotted proportional to the number of intervals the measurement represents. In this way, up to six days of data gathered at the rate of one measurement every 15 min can be displayed on a single plot as shown in Fig. 1 and the detail in the most recently acquired data is preserved. Furthermore, only n + 1 words of core memory are required to store 2^n measurements that are to be presented in this form. An algorhythm for arrangement of successive data values in this type of table is presented at the end of the paper and Table 1 shows the contents of each cell in the table after 12 entries. To provide scaling for a bar graph, horizontal lines are drawn through the maximum and minimum bars and labeled, and the short horizontal lines represent the maximum and minimum values contributing to the average represented by the height of each

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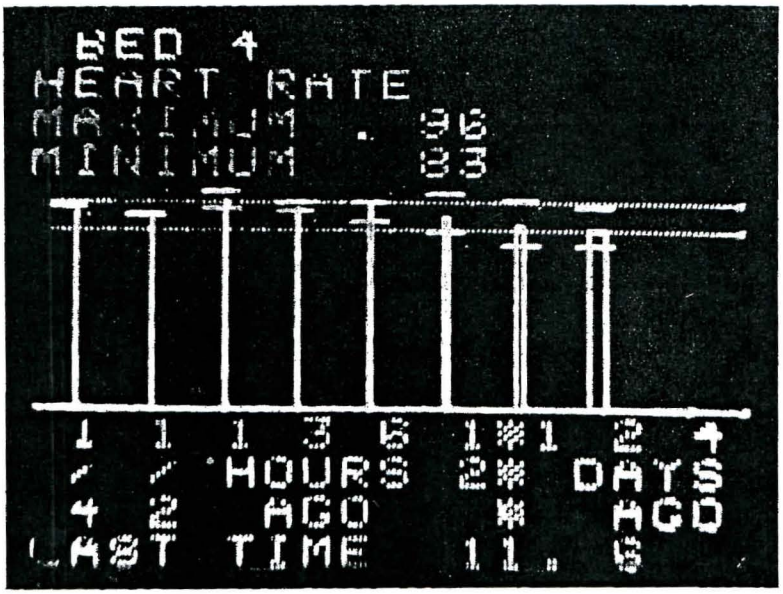

FIG. 1. Bar graph display of data from patient in an intensive care ward two days after surgery (see description in test).

bar. In the actual use of this type of log and display system on an intensive care ward it became necessary to provide a means for editing the data by deleting values representing invalid measurements such as might result from instrumental failure

TABLE 1

SEQUENCE OF CELL CONTENTS FOR FIRST 12 MEASUREMENTS

I	Cell (1)	Cell (2)	Cell (3)	Cell (4)	Cell (5)
1.	V_1				
2.	V_2	$\overline{V_1}$			
3.	V_3	V_1V_2			
4.	V_4	$\overline{V_3}$	$\overline{V_1V_2}$		
5.	V_5	V_3V_4	V_1V_2		
6.	V_6	$\overline{V_5}$	$\overline{V_1V_2V_3V_4}$		
7.	V_7	V_5V_6	$V_1V_2V_3V_4$		
8.	V_8	$\overline{V_7}$	$\overline{V_5V_6}$	$\overline{V_1V_2V_3V_4}$	
9.	V_9	V_7V_8	V_5V_6	$V_1V_2V_3V_4$	
10.	V_{10}	$\overline{V_9}$	$\overline{V_5V_6V_7V_8}$	$V_1V_2V_3V_4$	
11.	V_{11}	V_9V_{10}	$V_5V_6V_7V_8$	$V_1V_2V_3V_4$	
12.	V_{12}	V_{11}	V_9V_{10}	$\overline{V_1 \cdots V_8}$	

or a damped arterial pressure wave. To accomplish this it was only necessary to provide a convenient means for storing zero in the cell containing the invalid data. The algorhythm is modified so that each cell of any pair to be averaged is first checked for zero and if zero, only the other value is used to represent the average. In this way any cell once set to zero is soon replaced by appropriate values and does not distort the trend plot as it might have had the invalid values not been deleted.

Even in the case where data points are collected at irregular intervals, this same algorhythm may be used to arrange and display data. Since "*I*" in the algorhythm is the index of the number of samples collected at regular intervals, it can just as well represent the number of intervals even though more or less than one data value may be measured in any one interval. If no value is obtained, the value for that interval is set to zero and treated in the same way by the algorhythm as a value which has been deleted by editing. If more than one value is available in a given interval, these are averaged before being entered into the table. For example, during open heart surgery, cardiac output values cannot be obtained during that part of the procedure when the patient is on the heart-lung by-pass machine. It is important, however, when measurements are taken again that the surgeon and anesthesiologist be able to see the current state of the patient relative to his circulatory status prior to by-pass. The zero bars (absent vertical deflection) indicate the time of surgery. The basic time increment in the operating room version of the program is two minutes instead of fifteen minutes.

```
    Read Value
    I = I + 1
    L = I
    LI = -1
    IF (I-1) 12, 12, 1
1.  LI = LI + 1                    Log Base 2 of I
    L + L/2
    IF (L) 2, 1, 2
2.  IF (2**LI-I) 4, 2, 4
3.  Cell (LI+1) = Cell (LI)
4.  LJ = LI
5.  JJ = 2**(LJ) + 2** (LJ-1)
6.  IF (JJ-I) 8, 7, 9
7.  Cell (LJ+1) = (cell (LJ) - cell (LJ+1))/2
    go to 11
8.  JJ = JJ + 2**LJ
    IF (JJ - 2**(LI+1)) 6, 9, 9
9.  IF (I/2**LJ * 2** LJ-I) 11, 10, 11
10. Cell (LJ+1) = cell (LJ)
11. LJ = LJ-1
    IF (LJ) 12, 12, 5
12. Cell (1) = value
```

Of the variety of data displays provided to physicians, surgeons and nurses involved in making decisions with respect to the recognition and treatment of physiological disturbances in critically ill patients, this type of bar graph display has proven most useful. The reasons for that appear to be (1) it can be generated without the reviewer having to specify time limits for the display (requires only two choices, one for the bed number of the patient and the second to choose from a list the variables to be displayed), (2) the display format reveals trends at a glance, (3) the number of points (bars) in the display is small compared to the amount of original data represented, and (4) the time required to generate the display is minimized since a table of data for any variable having a one to one correspondence to the bars to be graphed is always available. Furthermore, display of the second or any subsequent variable can be obtained by pressing the numbered button corresponding to the next desired variable. Since, however, this system is designed to optimize the use of the data for decision making at a particular point of time, it does not substitute for a record of all the data if this data is to be used for after-the-fact analysis and correlation with discrete events such as drug administration.