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TITLE	STAP-8; SPIKE TRAIN ANALYSIS PROGRAM
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STAP-8; SPIKE TRAIN ANALYSIS PROGRAM

DECUS Program Library Write-up DECUS NO. 8-342

1. ABSTRACT

STAP-8 is a subroutine package for basic statistical analysis of stochastic point processes, written in PDP-8's PAL symbolic assembler language and available as a machine language perforated tape in binary format. Main effort was not made on sophisticated statistical techniques, but rather on a easy to control, variable program library, including CRT-display, paper tape output and teletype listings.

2. REQUIREMENTS

Storage - The package occupies all of the basic 4K core memory's locations, except the last page (BINLOADER/MONITOR). During load procedure, the package's analysis programs are saved on a full DF32 random access disk file track, service and I/O routines only rest in core permanently. Saved core space will then be loaded with DEC's basic floating point package and again saved on the lower half of a second DF32 track. (For detailed storage information, see MEMORY CHART appendix.)

Equipment - Basic PDP-8, 4K core memory; EAE extended arithmetic element; DF32 random access disk file (3 tracks); AXØ8 laboratory peripheral; CRT display unit.

3. USAGE

3.1 Loading - The package may be placed in memory either by the use of the Binary Loader or the system monitor's equivalent .LOAD.

NOTE: - Throughout this STAP-8 manual, machine language memory addresses and instruction codes are written in a four-character octal format !

The user with little or no experience may therefore make use of the octal-binary conversion table, listed below.

Ø	ØØØ	4	1ØØ
1	ØØ1	5	1Ø1
2	Ø1Ø	6	11Ø
3	Ø11	7	111

Now, to load STAP-8 proceed step by step as follows:

.1 Set PDP-8 front panel switch register (SR) to 76ØØ, then depress LOAD/ADD and START.

If the teletype outputs a ".", continue as in step .2! Else, consult the ERROR DIAGNOSTIC part of this manual!

.2 Type .LOAD
*IN-T:
*
*OPT-2

ST=34ØØ

NOTE: - Each line should be terminated with a RETURN command; wait until monitor types the next option request code!

.3 LOAD responds then, typing an upward arrow. Turn low-speed reader control (LSR) to position FREE and put STAP-8 paper tape in the reader.

.4 Type CTRL/P and turn LSR control to START. The loader will now read the tape and halts after checking the final checksum. If no checksum halt occurs, i.e., if the reader continues until the tape end has passed through, consult ERROR DIAGNOSTIC part!

.5 Turn LSR to FREE, reload STAP-8 paper tape, depress CONT, type CTRL/P and again turn LSR to START.

.6 .LOAD performs second-pass loading and again shows halt after checksum diagnostic.

.7 Turn LSR to FREE, depress CONT and type CTRL/P.

.8 Program control now turns over to STAP-8 disk save subroutine, which introduces itself by the following character string output:

SET SR FOR LOADING MODE / THEN CONTINUE

.9 Set switch register to 76ØØ and depress CONT. STAP-8 analysis programs will be saved now on a full DF32 disk track, and, after transfer complete control returns to the system's monitor, which again responds with a ".".

.10 Proceed now as in step .2, but replace the restarting address by:

ST=3447

.11 Procedures for two-pass loading the DEC 8-5-S/A or equivalent DEC 8-25-F/A floating point package are the same as described in step 3 - 7.

.12 After typing the last CTRL/P, control turns over permanently to STAP-8; string output announces:

PROGRAM LOADED / SELECT SUBROUTINE:
TYPE "*" AND CODE:

and lists the mnemonics of the package's 11 analysis programs available!

3.2 BINLOADER mode

If the system's monitor fails to work (see ERROR DIAGNOSTIC), STAP-8 may be loaded by the use of the RIM/BIN loader; proceed as in the steps listed below.

.1 * Toggle in the RIM loader, using the front panel switch register and the instruction codes listed on the left side of the panel!

.2 Set SR to 7756, depress LOAD ADD and START. Put the BINLOADER paper tape in the reader and turn LSR control to START.

.3 After the reader halts at the end of tape (no checksum diagnostic occurs!) depress STOP, set SR to 7777, depress LOAD ADD and START.

.4 Put the STAP-8 paper tape in the reader and turn LSR control to START. The BINLOADER places the program in the memory during <u>one-pass</u> only; a checksum halt should occur before end of tape has passed through!

.5 Set SR to 34ØØ, depress LOAD ADD and START; the teletype then should print the message mentioned in step 3.1.8

.6 Set SR to 7777 and depress CONT and then put the DEC 8-5-S/A or DEC 8-25-F/A floating point package in the reader, turn LSR control to START.

.7 After one-pass loading and checksum halt, set SR to 3447, depress LOAD ADD and START. The teletype output will be the same as mentioned in step 3.1.12 before!

3.3 - Operating Procedures

3.3.1 Program Flow

There is no HLT (halt) instruction in any part of the program, so the user will be discharged of front panel control operations, except for AXØ8 interface connections. The only way to control the program flow is realized by the mean of teletype 'shorthand' intercommunication . This will avoid hazardous destroying of program instruction by the user, setting incorrect switch register or control keys. <u>If the RUN indicator on the panel is turned off, the program control has executed a HLT instruction, and the STAP-8 program flow is broken</u>.

NOTE: - NEVER TRY TO RESTART THE PROGRAM, BUT RELOAD IT AS DESCRIBED IN 3.1!!

3.3.2 Program States

The program flow may be divided in three states with respect to the teletype intercommunication.

OLS - (Off-line state) Teletype keyboard information is not sensed during program evaluation and therefore will be ineffective on program flow.

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* For details, see description in PDP-8's software manual!

PRS - (Program request state) Program control turns over to the teletype input subroutine and expects the user to type a message. Control will not return until message terminating RETURN has been typed!

URS - (User request state) During program evaluation, the teletype input flag periodically will be sensed for a user request, which will cause a jump to the teletype input routine (see PRS).

3.3.3 Teletype Intercommunication

At the end of loading procedure, i.e., after instruction code mnemonics listing completed, control turns to PRS (see 3.3.2) and expects the user to type:

- a leading "*" ,

- one of the three-character instruction codes,

- and the terminating RETURN key!

This calling sequence will load the corresponding program from its save area on DF32 disk into core memory locations 34ØØ - 3577, and program evaluation continues immediately at 34ØØ. The program will introduce with an identifier label and continue with comment or request printout, or start data processing.

This is the general rule how to monitor program flow control; further details are mentioned in section PROGRAM DESCRIPTION.

Also, error messages may occur, discussed in the section ERROR DIAGNOSTIC.

4. PROGRAM DESCRIPTION

STAP-8 is a collection of subroutines; a part of it, composed of input-output, CRT display, format-conversion and other service programs may not be controlled or used through teletype intercom command mode, and therefore are not discussed below.

The 11 subroutines, referred to as ' the program ' which compose the 'core' of STAP-8 package and compute some of the elementary statistical measures of interspike time interval series, are described and discussed in detail.

Although the programs were written for neuronal 'spike' potential analysis, and therefore make use of the versatile AXØ8 laboratory peripheral, a STAP-8 version will be available, where raw data input consists of any digital data files up to 1Ø24 12-bit words each. A data word will then be interpreted as a positive integer in the range of Ø to 4Ø95, representing a time interval between two successive events of a series, considered to be the realization of a stochastic point process!

4.1 OPT - OPTions

This program includes output and service subroutines for various analysis extensions.

OPT introduces with label and colon printout, and expects the user to select and type (PRS) one of the legal option codes listed below, and a terminating RETURN!

RC - AXØ8 RC-clock time base calibration.

ST - AXØ8 Schmitt-Trigger input level control.

DN - Delete old N and accept new interval file range.

P - Punch binary coded paper tape output.

L - List statistical measures of central tendency.

Non-legal codes will again cause the label and colon printout, i.e., program restart! If the code has a leading "*", the command decoder interprets this as a user's program request; OPT will then be left and a new program loaded!

4.1.1 RC

Code terminating RETURN initiates the program to set AXØ8 digital output SØ from Ø to -3 V at the AXØ8 RC-clock pulse rate. Link SØ output to an oscilloscope, set the vertical amplifier to 1 V/cm and the time base generator to the range desired. The time base is equal to the duration of <u>one</u> positive or negative going square-wave pulse. Calibrate the square-wave by the use of RC-clock control potentiometers on the AXØ8 front panel!

NOTE: - TIME BASE CALIBRATION REQUIRES CAREFUL ATTENTION. THE RESULTS OF STATISTICAL COMPUTATIONS ARE RELATIVE AND BASED UPON THE TIME UNIT SELECTED!

4.1.2 ST

Code terminating RETURN initiates the program to type the input channel request "S:", which the user has to respond, typing the Schmitt-Trigger input number (1, 2 or 3) he wants to test, and terminating RETURN.

The program then senses the state of the Schmitt-Trigger selected, and, if set to 1, produces a -3 V pulse (0.5 msec duration) at SØ. SØ may be linked to an oscilloscope and, if there is a dual beam option, the original spike train may be compared with that, recorded by the Schmitt-Trigger.

Schmitt-Trigger level will be set from Ø to -2.5 V by Schmitt-Trigger potentiometers on the AXØ8 front panel!

NOTE: - BOTH RC AND ST OPTIONS MAY BE INTERRUPTED, STRIKING ANY KEY ON THE TELETYPE KEYBOARD. THIS WILL CAUSE A NEW LABEL AND COLON PRINTOUT!

4.1.3 DN

Code terminating RETURN initiates the program to type the new file range request "N:", which the user will have to respond, typing the upper boundary of the next spike train to be processed and terminating RETURN!

Core location ØØ22 will then be loaded with the new N's two-complement value; the value of the old N is lost!

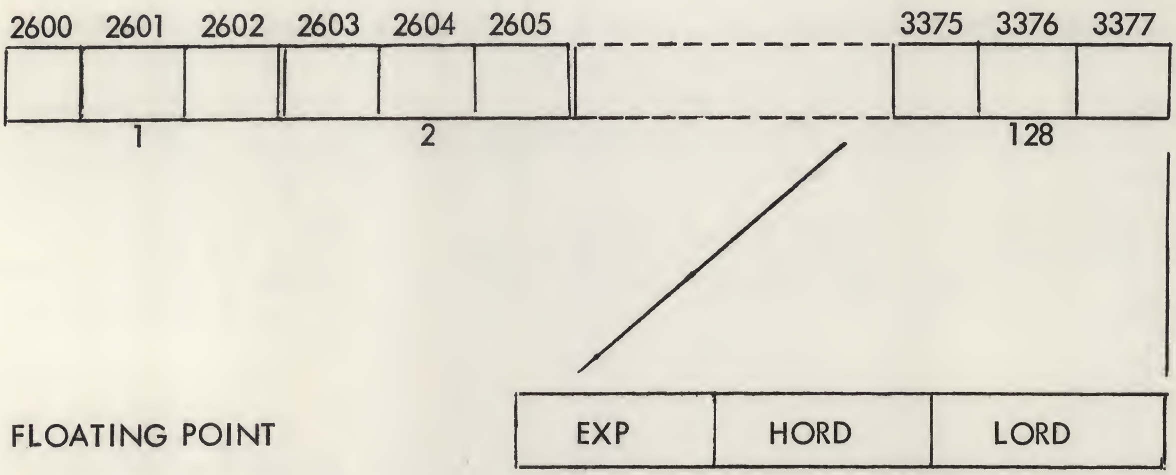
NOTE: - N SHOULD BE LESS THAN 1Ø24!

4.1.4 P

Code terminating RETURN initiates program request typeout "I:". The user is expected to design the data file in core memory to be punched on paper tape in binary format.

I:R Output source is the 128x3 word register. It contains the integer (floating point) results of statistical computations. The memory chart below and program descriptions of the corresponding statistical measures will help the user to plan additional off-line analysis programs.

REGISTER MEMORY CHART



FLOATING POINT

Serial correlation coefficients (SCG) will be computed and stored in floating point format:

EXP	11-bit exponent plus sign bit
HORD	High-order 11-bit mantissa plus sign bit
LORD	Low-order 12-bit mantissa

INTEGER

Program	AUT CCR STH	CMD CPD	(SVF)

Unsigned 12-bit integer results will be stored in the 1st, 2nd or 3rd word of each 3-word block as labeled above.

I:T:1 - I:T:2 - Output source is one of the 1Ø24 word time interval data fields labeled 'TRAIN 1' and 'TRAIN 2' respectively. If less than 1Ø24 spikes have been recorded (counted), non-required locations are set to zero and punched too! (See program description IC1 and IC2!)

NOTE: - File designation terminating RETURN initiates the output subroutine to punch a 1 ft. leader tape. Therefore the Low Speed Punch (LSP) control should be turned ON previous to the RETURN instruction!

NOTE: - Non-significant character printout during data punch output is due to parallel teletype/punch logic and is of no importance.

At the end of data output, a 1 ft. trailer tape is punched. The LSP control should then be turned OFF, otherwise all subsequent teletype communication is punched on paper tape!

Program control initiates a new "OPT:" printout and returns to PRS!

Each 12-bit word requires two consecutive punch columns. The first half word is punched on tracks 1 - 6 of the first, the second half word on the same tracks of the second column!

NOTE: - MAKE SURE THAT EACH PAPER TAPE IS LABELED WITH SUFFICIENT DATAS FOR ADDITIONAL PROCESSING!

4.1.5 L

Code terminating RETURN initiates program request typeout "T". The user is expected to design one of the time interval data fields, referred to as 'TRAIN 1' and 'TRAIN 2' respectively, typing a "1" or "2" and terminating RETURN.

The program then evaluates five of the most required statistical measures of central tendency.

N - Number of intervals (spikes) of the train designed.

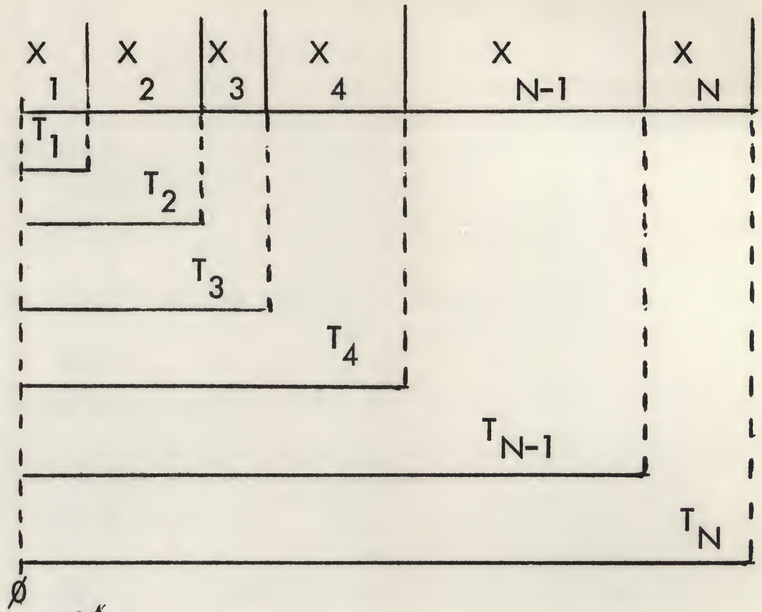
T - Sum of time intervals, i.e., total record duration.

MU - Interval mean value.

S - Standard deviation.

C - Estimate of the coefficient of variation (having the value unity for an exponential population)!

Formulas of computation



$$T = \sum_{1}^{N} X_i = T_N$$

$$MU = T / N$$

$$S = \left(\sqrt{N . \sum_{1}^{N} X_i^2 - T^2} \right) / N$$

$$C = S / MU$$

Output format - Data output is in standard decimal floating point format.

+O.mmmmmmmE+ee

exponent (base 10)

mantissa (decimal)

Example (time base 0.001 sec)

N	+Ø.1Ø13ØØØE+Ø4	1013 spikes have been counted
T	+Ø.284Ø2ØØE+Ø5	over a period of 28,402 sec.
MU	+Ø.28Ø3751E+Ø2	Interval mean is 28,03751 msec
S	+Ø.1816645E+Ø2	with standard deviation 18,16 msec
C	+Ø.1177Ø67E+Ø2	Estimate of the coefficient of variation is 11,77 and indicates strong rejection of the Poisson hypothesis!

4/2 IC1 Interval Counter 1 channel
IC2 Interval Counter 2 channel

These two programs are AXØ8 interface monitor subroutines and perform digitalization of interspike time intervals in series of 1024 events (spikes) per channel.

The programs introduce with label and input linkage mnemonics.

AXØ8 Schmitt-Trigger W501 inputs S1 and S2 accept negative going, negative spike pulses. The switching thresholds can be varied over the range of 0 to -2.5 V by front panel potentiometers (see program OPT, option ST). Schmitt-Trigger input S3 accepts the counter start pulse which may be set either by an optional pulse device or by a synchron pulse track on the tape recorder device. In either case, the pulse specifications mentioned above should be recognized!

Start pulse enables the RC-clock and initiates counting procedure. Each event (spike) recorded will save the clock counter value on consecutive train storage locations as a 12-bit unsigned integer, that represents the RC-clock pulses counted during the last interval. No zero interval will occur!

NOTE: - IF ANY TIME INTERVAL EXCEEDS 4095 (multiplied by the time base!) AN OVERFLOW ERROR MESSAGE WILL OCCUR!

To avoid this interrupt make sure that the RC-clock calibration allows counting of the longest interval recorded ! (See 4.1.1)

IC1 counting procedure terminates:

- when 1Ø24 or N 1Ø24 (see 4.1.3) time intervals have been digitalized and stored.

- when 1Ø24 or N intervals have been processed by <u>one</u> of the two counters in IC2 mode.

- after OVERFLOW message printout.

- when a data break has occurred, i.e., when the tape recorder playback has been turned off. (This will cause an OVERFLOW error message because the time period following the break point will be interpreted as an interval which exceeds 4095!)

Non-required storage locations are set to the value zero and the trains then saved on a full (or half) DF32 disk track.

Disk transfer completed will cause an end-of-job mnemonic typeout, and program control turns on PRS to receive the next program code.

The user is recommended to proceed then with program OPT, option L, to get general information about raw data. This will be helpful to plan additional analysis!

4.3 Autocorrelogram

This program computes the order-dependent statistical measure involving time intervals between non-successive events, known as the estimates of the renewal density function or autocorrelation function.

Principle of operation: The range of observed interval lengths (see X SCALE FACTOR) is divided into 128 bins of equal class size d; if the i-th observed interspike interval X_i satisfies the inequalities

$$(j-1).d < X_i < j.d$$

then that interval is placed in bin j of the histogram. The bins are numbered 1, 2, . . . , 128.

For higher-order density estimates, the inequalities hold

$$(j-1).d < X_i^n < j.d$$

where

$$X_i^n = \sum_{k=i}^{i+n-1} X_k \qquad\qquad i = 1, N-\underline{n}+1$$

and the estimate is of order n!

So n histograms have to be evaluated and summed up. To compute the average range of a n-order autocorrelation estimate, use the rule

$$T_n \simeq n.MU$$

(for MU, see program OPT, option L)

Since the renewal density is the sum of all orders, i.e., $n \rightarrow \infty$, the estimate error will decrease for increasing n!

Contradictory to this rule is the fact that higher order histograms will flatten out due to the finite number N of the interval sample.

So, for example, if you take n = N, the n-th histogram will be only one bin (the last one) incremented, which is of less weighting value for the overall estimate!

n=1 n=N/2 n=N

(The figures show the k-th order histograms for k = n)

Use - Code terminating RETURN initiates label and request printout.

TRAIN - The user is expected to design the spike train to be processed (Typing 1 or 2) and terminating RETURN!

LAG ORDER - The user is expected to type the order n of the autocorrelation function discussed above.

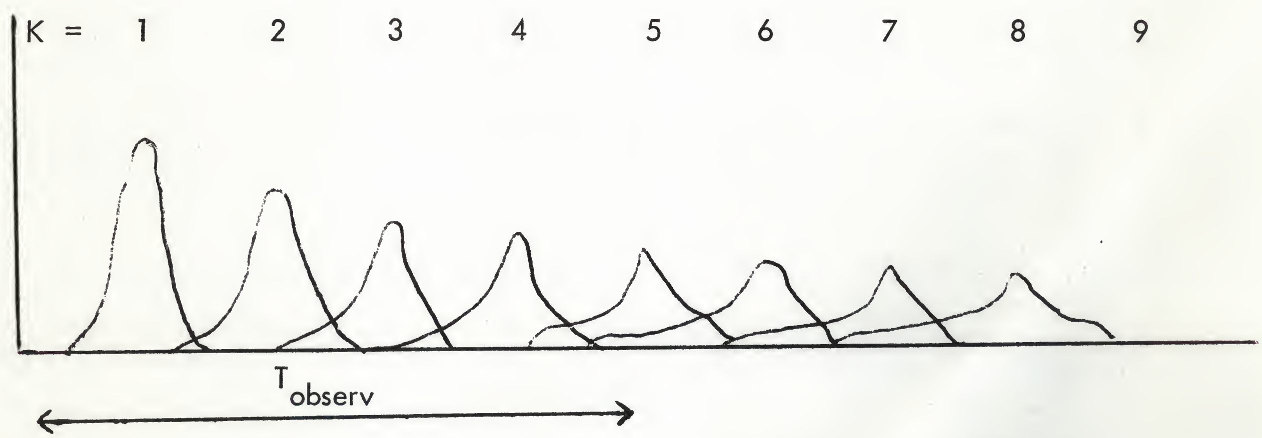
LAG ORDER 1 initiates computation of the first-order autocorrelogram estimate, known as "interval histogram"!

X SCALE FACTOR - The user has to specify the time of observation necessary for analysis, according to the table listed below: (TIME BASE 1 mSEC)

X SCALE FACTOR	CLASS WIDTH	TIME OF OBSERVATION
0	1 mSEC	128 mSEC
1	2	256
2	4	512
3	8	1024
4	16	2048
5	32	4096
6	64	8192
...	...	....

Terminating RETURN then initiates processing of n histograms (see principle of operation) which are summed up in the first words of a 128 x 3 integer array (see REGISTER MEMORY CHART, 4.1.4). After processing completed, AUT calls up the histogram display subroutine HST (see 4.4).

The user may become troubled when he will determine the order n of an autocorrelation analysis. As demonstrated above, each order will shift the histogram to the right with a delay of about the mean interval time MU.



If n = 5, the user will have to expect an estimate error (which may be small at all) due to the classes lost of 6, 7 or even 8 order histograms! To avoid this error, start the analysis with the n calculated from the formula given in the section "principle of operation', then recall AUT and increase n until the autocorrelation estimate will show no significant variation.

Analysis - The autocorrelation is a probability density function and specifies the probability of encountering any event (spike) as a function of time after a given event (spike).

The first-order autocorrelation function, i.e., the "interval histogram" specifies the probability of encountering the next event (spike) as a function of time after a given event (spike)!

If the series of spikes is the realization of a Poisson process, the autocorrelogram will flatten out to the value

$$\lambda = \frac{1}{MU} \quad , \quad t \rightarrow \infty$$

For detailed information see REFERENCES APPENDIX in this manual!

4.4 HST - Histogram Display Subroutine

HST may be called in memory either by the user or autonomously by programs AUT, CCR, and STH. HST introduces with label - and

Y SCALE FACTOR

request printout. The user is expected to specify the vertical counting range for histogram class display. He may use the following table:

Y SCALE FACTOR	Y RANGE
0	0 - 127
1	0 - 255
2	0- 511
3	0- 1023
4	0- 2047
5	0- 4095
...	....

The program then displays 128 classes of counts, the class width pre-selected by programs AUT, CCR, and STH.

If one or more classes reach the top of the display area, which is marked by half- and full-scale dots, the user should recall HST, which is in PRS state, and then increase the Y SCALE FACTOR by one. The display will then be scaled by a factor 2 !

NOTE: - THIS PROCEDURE MAY BE REPEATED UNTIL NO CLASS EXCEEDS THE UPPER SCALE RANGE LIMIT!

4.5 CMD - Cumulative Distribution Function

Principle of operation - The program computes and displays the estimate of the probability distribution

$$F(t) = \int_0^t f(T).dT$$

where f(T) is the probability density function discussed in 4.3!

The program evaluates

$$F_i = \frac{1}{N} \sum_1^i n_i \qquad i = 1,128$$

from the class frequencies n_i stored in the first column locations of the register array (4.1.4) and deposits F_i in the second column locations of the register. CMD will therefore make reference to programs already evaluated, as AUT (LAG ORDER 1) or STH!

Use - Code terminating RETURN is immediately followed by CRT display and a vertical scale grid, marked from 0 to 1 by steps of 0.05!

NOTE: make sure that 'sth' or 'aut' 9lag order 1) HAVE BEEN PROCESSED BEFORE USE OF "CMD" !

Analysis - The estimates of the probability distribution is known too as "cumulative frequency distribution", and measures the probability that an event (spike) will have occurred by time t from the last event (spike). Then, most frequently, the equality listed below is used:

$$p(T_1 \leqslant T < T_2) = F(T_2)-F(T_1)$$

It will give the probability that the interspikes interval time will be in limits T_1 and T_2 respectively.

4.6 CPD - Conditioned Probability Density

Principles of operation - CPD computes and displays an estimate of the order-independent conditioned probability (postpulse probability, hazard function).

$$\varphi(t) = \frac{f(t)}{1-F(t)}$$

The program evaluates

$$\varphi_i = \frac{n_i}{N - \sum_1^i n_i} \cdot \frac{1}{\Delta T} \qquad i = 1,128$$

where

n_i = interval class frequency

N = number of intervals counted

ΔT = interval class width

Use - Code terminating RETURN is immediately followed by CRT display and the grid, described in 4.5!

NOTE: - MAKE SURE THAT "AUT" (LAG ORDER 1) OR "STR" HAVE BEEN PROCESSED BEFORE USE OF "CFD"!

Analysis - The condition density function specifies the probability density of encountering the next event (spike) at the time t after the last event (spike), given that there was no event prior to the time t!

For a Poisson process, the condition density function is a constant.

$$\varphi(t) = \lambda = \frac{1}{MU}$$

4.7 SCG - Serial Correlogram

Principle of operation - The serial correlogram is the set of the serial correlation coefficients

$$R_j = \frac{1}{\sigma^2} \cdot \mathcal{E}((X_i - \mu)(X_{i+j} - \mu)) \qquad j = ..,01,0,1$$

SCG computes 128 coefficient estimates

$$R_j = \frac{\frac{1}{N-j}\sum X_i X_{i+j} - \frac{1}{(N-j)^2}(\sum X_i)(\sum X_{i+j})}{\left(\frac{1}{N-j}\sum X_i^2 - \frac{1}{(N-j)^2}(\sum X_i)^2\right)\left(\frac{1}{N-j}\sum X_{i+j}^2 - \frac{1}{(N-j)^2}(\sum X_{i+j}\right.}$$

for $j = 1,\ldots,128$

In this subprogram, all computation is performed in three-word floating-point mode. The coefficients are held in a 128-floating-point-array (see REGISTER MEMORY CHART, 4.1.4)

Use - Code terminating RETURN initiates label printout and request

TRAIN

The user is expected to design the spike train to be processed, typing a 1 or a 2!

The program is now running in OLS state for about 5MIN (job time depends on actual data file length N!) Processing complete, control turns on URS and initiates CRT display. 128 correlation coefficients are displayed, together with a scale grid, marked from -1 to +1 by steps of 0.1!

Analysis - Serial correlation coefficient analysis is explained with respect to the well-known joint interval density.

Joint interval times are displayed in the form of a scatter diagram, in which the length of a joint-pair of intervals is represented by abscissa and ordinate respectively.

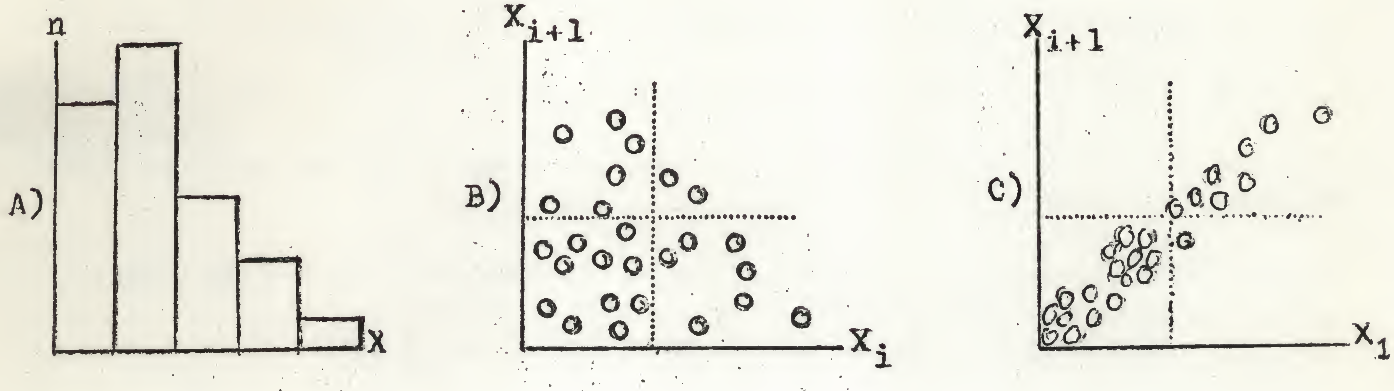
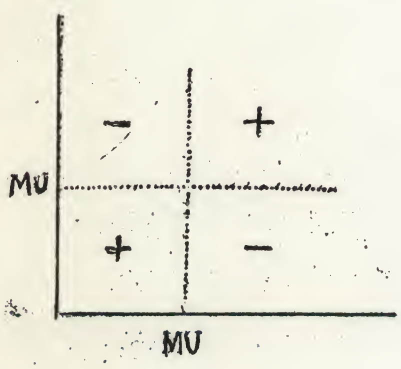


Figure A) shows an interval histogram of a set of 27 intervals; the same distribution was used to reconstruct two sequences, with scatter diagrams E) and C) for the joint interval distribution sketched above. Intervals of train B arise from a renewal process and therefore are drawn independently from the distribution A), the scatter diagram will look quite "random."

The intervals of train C arise from the same distribution, but have been arranged in a decreasing sequence; the related scatter diagram shows a "non-random" pattern.

The problem arises from 'subjective' pattern recognition and interpretation of more or less significant patterns, i.e., correlations. A quantitative measure of such a correlation is furnished by the serial correlation coefficient defined above, and we will illustrate the case for R_1, i.e., the joint interval serial correlation (for nonadjacent intervals the conclusions will be similar).



To illustrate the correlation product

$$c = (X_i - MU)\ (X_{i+1} - MU)$$

dotted lines on scatter diagrams mark mean interval times MU on both abscissa and ordinate and divide the diagrams' first quarter in four sets of scatter points (i.e., joint interval pairs).

The related correlation products will be positive or negative signed according to the set, the joint pair (X_i, X_{i+1}) belongs to:

For the sequence C this means, that almost all (except one) products are positive, and the correlation coefficient will not be far from the standard deviations square value.

For the independent sequence B there will be almost the same number of positive and negative products to be summed up, and the coefficient therefore to close to the value zero !

The expected value of the serial correlation coefficients of all orders (1 - 128) is approximately zero if the intervals are drawn independently from a common distribution.

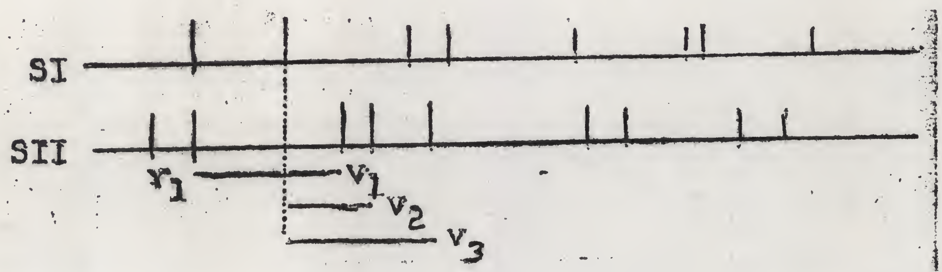
Positive contributions to serial correlation coefficients are due to long-term trend in data

For detailed analysis see REFERENCE APPENDIX.

4.8 CCR - Cross-Correlogram (Cross Correlation Histogram)

Principle of operation - The cross-correlation histogram is a measure to test whether two spike trains are independent.

Train I is the reference train or, in terms of the 'poststimulus time histogram', the "stimulus train." Forward and backward recurrence times are then counted in train II relative to any event (spike), or ' stimulus,' in train I. A histogram will be computed for all spikes in train 1 to <u>all</u> spikes in train II



Use - Code terminating RETURN initiates label and request printout.

X SCALE RACTOR -

The user has to specify the time of observation. Forward and backward recurrence times will be counted, so the origin of the time scale will be between class NO. 64 and NO.65.

(TIME BASE 1 mSEC)

X SCALE FACTOR	CLASS WIDTH	TIME OF OBSERVATION
0	1 mSEC	- 64 mSEC — + 64 mSEC
1	2	- 128 — + 128
2	4	- 256 — + 256
3	8	- 512 — + 512
4	16	- 1024 — +1024
...	...	.... — ....

Analysis - The cross-correlation histogram is an estimate of the cross-correlation function $X_{12}(t)$, defined as the probability density of encountering any event (spike) in train 2 as a function of time after a given event (spike) in train 1.

The cross-correlation histograms have two uses:

- as a corroboration of independence, indicated by a flat cross-correlogram.

- as a means of exploring suspected interactions, indicated by positive or negative going elevations (peaks), with respect to the reference level.

The following symmetry relationship for the cross-correlation holds:

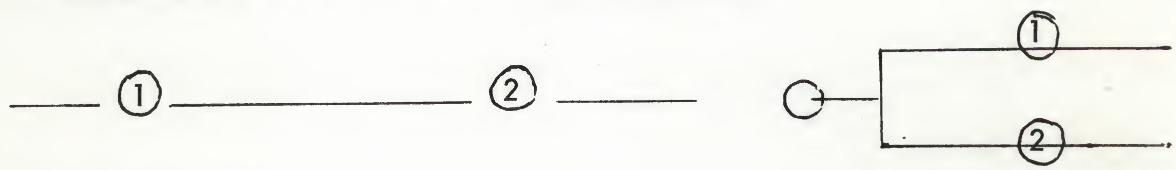
$$\frac{X_{12}(t)}{MU_1} = \frac{X_{21}(-t)}{MU_2}$$

where MU_1 and MU_2 are the mean interspike intervals of train 1 and 2 respectively. For this reason, the cross-correlation estimate is measured in only one direction, from train 1 to train 2, but for both positive and negative values of t.

Prediction of correlation or independence should be carefully examined; errors arise from different sources, some of them being mentioned below.

- independently firing pacemakers of near the same frequency exhibit peaks in the cross-correlation histogram, which oscillate with the period of the pacemaker neurons'.

- distinction between interaction (direct or indirect) and common input.



- weak dependence will be indistinguishable from sample 'noise''.

- combinations of positive and negative interactions may coincidentally combine and evoke flat cross-correlograms, i.e., prediction of independence will be guessed'.

For further and detailed analysis, see REFERENCE APPENDIX '

4.9 TIS - Time Interval Sequence

Principle of operation - Most of the statistical analysis done will deny the 'null hypothesis', but rather leads to the prediction of 'dependence', 'functional relationship' or 'significant patterns'. Although these measures will do so, they will not give any information about the source of the relationship or the pattern itself. This information is lost during computation and up to the time now, no ' all- round' pattern-recognition program exists'.

In practice, most of the prediction concerned with these questions are drawn out from raw data, i.e., from the original sequence of events (spikes).

To help the user, this program will display the interval times between adjacent events as a function of their number of occurrences in the sequence of events. This is done on a small area, compared with any other record representation, and the intervals are shown as ordinate values, a more accurate form than any numerical listing.

Use - Code terminating RETURN will cause label and request printout:

TRAIN
_

The user is expected to specify the sequences of events (train) to be displayed. Control immediately turns on URS, and the sequence of intervals appears as a set of dots on the CRT device.

The sequence and the vertical scale factor may be controlled on-line by the use of ADC control knobs on the AXØ8 front panel as follows:

ADC 1 - The first interval, out of the sequence to be displayed, may be specified, its number of occurrence appears in the display record field "C" as an even integer in the limits of Ø to 1Ø22.

ADC 2 - Up to 512 intervals may be displayed simultaneously. This upper limit may be scaled by powers of 2, down to the smallest set of 4 consecutive intervals. The specified number appears in the field "X" of the display record.

ADC 3 - Vertical timescaling by powers of 2 is performed by the use of the third control knob. Realtime values may be calculated with respect to the time base, selected during data conversion (see OPT, 4.1.1). Fullrange numbers from 64 up to 4096 time units are optional and appear in field "Y" of the display record.

NOTE: - THE SUM OF THE TWO CONTROL COUNTERS "C " AND "X" SHOULD BE CHECKED TO HAVE A VALUE LESS THAN THE TOTAL NUMBER OF EVENTS (SPIKES) COUNTED FOR THE TRAIN SPECIFIED ($N \leq 1024$).

Otherwise, non-significant CPU core data will be interpreted and displayed as time intervals too!

4.10 STH - Stimulus-related Time Histogram (Post-stimulus time histogram)

Principle of operation - Forward recurrence times are counted with respect to each stimulus event. The recurrence times then are re-arranged in a histogram. This post-stimulus time histogram is an estimate of the cross-correlation function described in section 4.8, but with the restriction that calculations are performed for positive times and in one direction only.

Use - Code terminating RETURN initiates label and request printout:

X SCALE FACTOR _

The user is expected to specify the time of observation, according to the table listed in section 4.3!

Request terminating RETURN initiates data linkage mnemonics printout:

S1 stimulus events data channel

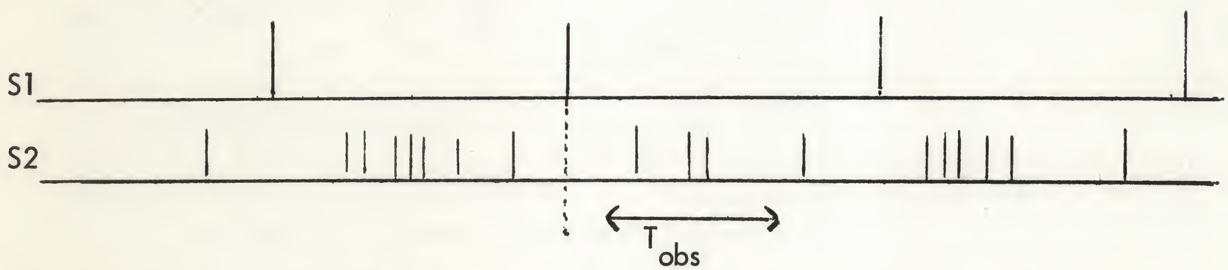
S2 stimulus-related events data channel

S3 start pulse channel

NOTE: - STH is an on-line analysis subroutine and will not process interval sequences counted by the use of program IC2!

The counter stops, when either 1Ø24 events from input channel S2 or N stimulus events from input S1 have been recorded. The number of stimuli (N) must be specified previous to the use of STH (see program OPT, 4.1.3).

With increasing time of observation, more events are counted after a given stimulus; though, by the limit of 1Ø24 (which will be most frequently reached before N !) the number of stimulus events counted will decrease.



The program autonomously calls subroutine HST for histogram display, when the counting procedure has been terminated.

Although the program was designed for on-line analysis, the post-stimulus times counted will be saved as a disk file and may be called in core memory for computation of the measures of central tendency (program OPT 4.1.5) later on.

Analysis - As mentioned before, the STH histogram is an estimate of the probability density function equivalent to the cross-correlation function between the train of stimuli and the train of spikes. If the stimulus has no effect, the histogram will be flat.

5. CRT Display and Photo Recording

The package was designed for on-line application and therefore high priority was given to the CRT information display concept.

Each analysis program outputs data in the form of a CRT graphic, always composed of:

- a record (head)

- a scale grid

- and a function or histogram plot

The scale grids and the functions have been mentioned and described in the section PROGRAM DESCRIPTION.

The display record is composed of a set of mnemonics and numbers, and was designed for photo record identification.

①			②		③
TIS	T:0002	X:0256	STAP-8	05	
	C:0098	Y:0128	30.5.69		

1. Program mnemonic refers to the program who's output is displayed.

2. Package mnemonic

3. Comment record field: 10 characters may be displayed in this field for additional user comments. During CRT display mode, program control always is in URS state, and therefore the teletype is sensed for comment or program code characters. The first key stroked CRT display is interrupted until the terminating RETURN key has been sensed.

4. Photo record counter: This two-digit decimal counter is incremented after the photo record sequence, described below, and may not be reset.

T Spike train number (with reference to Schmitt-Trigger inputs S1 and S2), specified as input data file for the running program.

C The scratch constant has a different meaning, according to the program running:

AUT	Lag Order n
CMD	-
CPD	-
SCG	Number of coefficients computed
CCR	-
TIS	First interval (no. of occurrences)
STH	Number of stimuli counted

X Indicates the full range of the abscissa and must be interpreted according to the running program either as a number or as a time (multiplied by the time unit).

Y Indicates the full range of the ordinate and must be interpreted either as the number of counts (histogram), a real value of a function (CMD, CPD, SCG), or a time as in program TIS!

NOTE: - IF THE INTEGER NUMBER OF EITHER THE RECORD FIELD "X" OR THE RECORD FIELD "Y" EXCEEDS THE VALUE 4Ø95, A DATA OVERFLOW OCCURS AND THE CHARACTERS ØØØØ ARE DISPLAYED!

In this case, the user should refer to the teletype record of the value missed.

5.1 Photo Record Sequence

S3 - If during the display sequence a -3 V pulse is sensed at input channel S3, the program control interprets the pulse as a user request for remote photo control. This option was designed for two reasons. First, function and histogram display have different sweep times (CRT refreshment), and therefore need different shutter interval (exposure time).

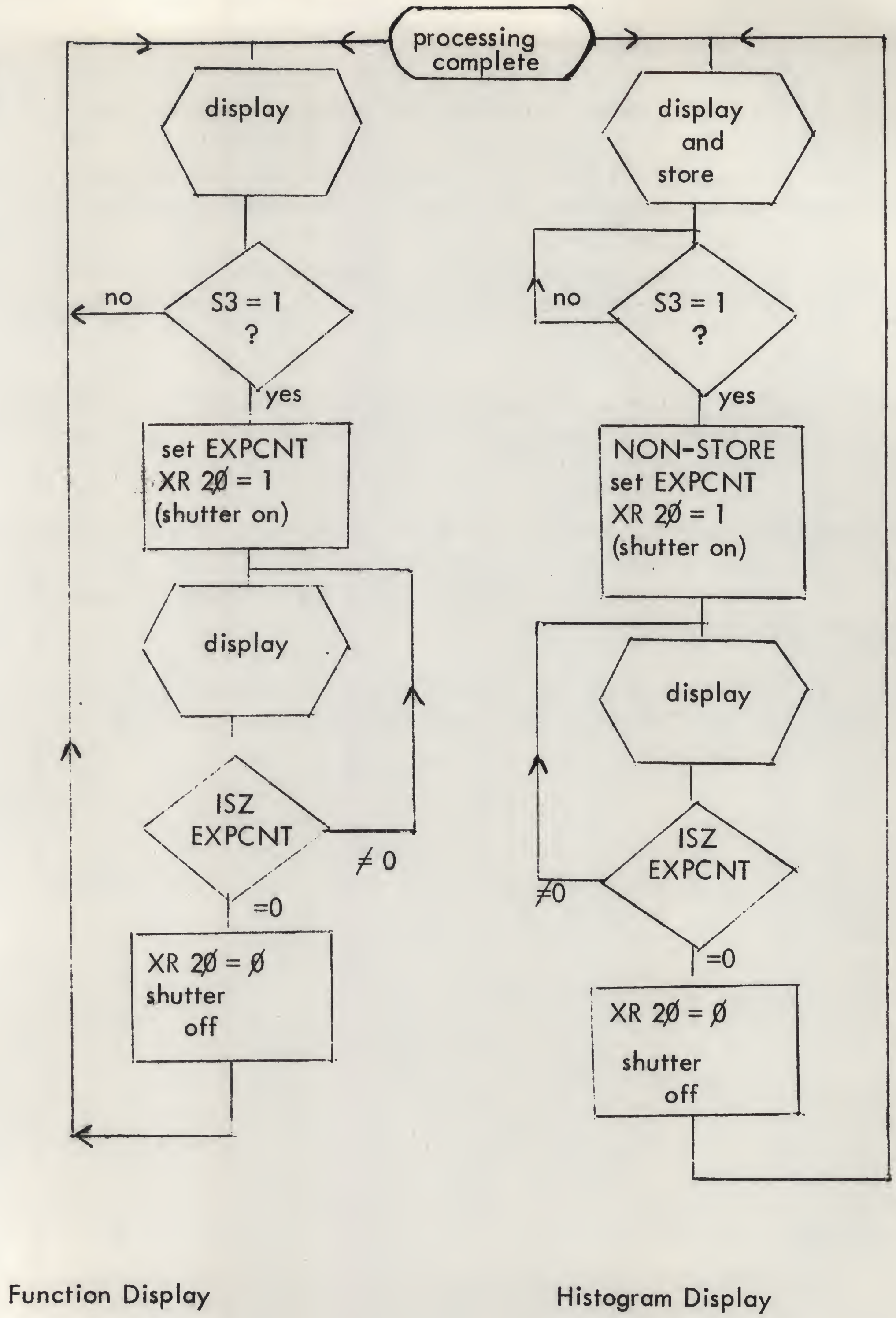
Second, there is a package version available, where all the histograms make use of a storage CRT device. This option is used to avoid CRT flicker, due to histogram refreshment intervals.

The record sequence initiated, CRT remote control is set to NON-STORE MODE to obtain clear-cut photo records. At the end of the record sequence, control again turns on STORE MODE.

XR 2Ø - The photo sequence exposure counter is incremented for each refreshment sweep. During this sequence, the AXØ8 output level option XR ØØ2Ø is set to the logic value 1 and cleared immediately after conclusion of the counter loop. This option may be used for photo remote control (shutter logic B).

NOTE: - THE EXPOSURE COUNTER (STORAGE LOCATION Ø322) MAY BE RESET ACCORDING TO THE CRT INTENSITY AND RECORD FILM SENSITIVITY AVAILABLE!

Photo Sequence Flow Chart



APPENDIX A REFERENCES

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G. P. Moore D. H. Perkel J. P. Segundo	Statistical Analysis and Functional Interpretation of Neuronal Spike Data Annual Review of Physiology, Vol. 28, 1966
D. H. Perkel T. H. Bullock et.al.	Neural Coding (NRP Work Session Report) Neurosciences Research Program Bulletin, Vol. 6, No. 3, 1968
P. A. W. Lewis	A Computer Program for the Statistical Analysis of Series of Events IBM Systems Journal, Vol. 5, No. 4, 1966, pp 202-
D. R. Cox	Renewal Theory Methuen's Monographs on Applied Probability and Statistics, 1967
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Chin Long Chiang	Introduction to Stochastic Processes in Biostatistics John Wiley, 1968

APPENDIX B

ERROR DIAGNOSTIC

Error diagnostic messages may occur and are listed and discussed below.

Loading procedure error messages are discussed in section ERROR DIAGNOSTIC of the PDP-8/I console manual!

TT intercom error messages

INCORRECT PROGRAM CODE

A character string with a leading "*" was checked to be incompatible with valid program codes.
State PRS

?

A character string was checked to be composed of more than 16 characters allowed.
State PRS

Disk transfer error messages

DF32 ERROR MESSAGE !

A DFSE skip request was missed during disk transfer. The error is due to hardware breakdown, and the systems engineer should be contacted.
State HLT (program flow interrupted)

Program error messages

OVERFLOW AT ØØØØ

The link bit was sensed for data overflow. The result of an arithmetic operation will not be valid.
State program continuation

IC1 at 3475
IC2 at 35Ø4 and 351Ø

(An interval counter has counted 4Ø96 time units)

CMD at 3462
(divisor smaller than dividend)

ZERO COUNT LOAD !

A counter location was initialized and set to the value O.
State PRS

OPT at 3425
AUT at 34Ø5
CCR at 34Ø7

A non-existent data file (spike train) had been specified for processing.

Program STAP-8

Page	1st A	last A	Content
0	0	177	CONSTANTS/SR POINTER/SEQ CODE LIST/SEQRDD
1	200	377	MESAGE/PHOTO/RDD/DFERR
2	400	577	MESSIN/OFLOW/OCTDUM
3	600	777	MASTER/BELL/BINDEC
4	1000	1177	DECBIN/WRT
5	1200	1377	TRANSF/GRID1/BINDUM/LOADTR/WC/CA/SAVE/LAYOUT
6	1400	1577	LABEL/SAVETR
7	1600	1777	ADISP/GRID2/ZERON
10	2000	2177	FLPOUT/READC
11	2200	2377	CHDSC
12	2400	2577	DECTBL
13	2600	2777	(BINARY PUNCH SA:2665)
14	3000	3177	
15	3200	3377	
16	3400	3577	NON-RESIDENT LOADER/DF32 SAVE/SEQUENCE/SA:3400
17	3600	3777	OPT I
20	4000	4177	OPT II
21	4200	4377	IC1
22	4400	4577	IC2
23	4600	4777	HST
24	5000	5177	AUT I
25	5200	5377	AUT II
26	5400	5577	CMD
27	5600	5777	TIS
30	6000	6177	CPD
31	6200	6377	SCG I
32	6400	6577	SCG II
33	6600	6777	CCR I
34	7000	7177	CCR II
35	7200	7377	STH I
36	7400	7577	STH II
37	7600	7777	SAVE AREA FOR RIM/BIN LOADER/MONITOR RESIDENT

Remarks LOAD STEP I

Program STAP-8

Page	1st A	last A	Content
0	0	177	ZERO-PAGE
1	200	377	SR
2	400	577	SR
3	600	777	SR
4	1000	1177	SR
5	1200	1377	SR
6	1400	1577	SR
7	1600	1777	SR
10	2000	2177	SR
11	2200	2377	CHDSC
12	2400	2577	DSCTBL
13	2600	2777	FLPBUF (128 3-WORD FLOATING POINT REGISTER)
14	3000	3177	FLPBUF
15	3200	3377	FLPBUF
16	3400	3577	RESIDENT SEQUENCE STORAGE LOCATION
17	3600	3777	
20	4000	4177	
21	4200	4377	
22	4400	4577	
23	4600	4777	
24	5000	5177	
25	5200	5377	
26	5400	5577	
27	5600	5777	8-5-S/8-25-F FLOATING POINT PACKAGE
30	6000	6177	8-5-S
31	6200	6377	8-5-S
32	6400	6577	8-5-S
33	6600	6777	8-5-S
34	7000	7177	8-5-S
35	7200	7377	8-5-S
36	7400	7577	8-5-S
37	7600	7777	SAVE AREA FOR RIM/BIN LOADER

Remarks LOAD STEP II

Program STAP-8

Page	1st A	last A	Content
0	0	177	ZEROPAGE
1	200	377	SR
2	400	577	SR
3	600	777	SR
4	1000	1177	SR
5	1200	1377	SR
6	1400	1577	SR
7	1600	1777	SR
10	2000	2177	SR
11	2200	2377	CHDSC
12	2400	2577	DSCTBL
13	2600	2777	FLPBUF
14	3000	3177	FLPBUF
15	3200	3377	FLPBUF
16	3400	3577	RESIDENT SEQUENCE STORAGE LOCATION
17	3600	3777	TRAIN 1
20	4000	4177	/
21	4200	4377	/
22	4400	4577	/
23	4600	4777	/
24	5000	5177	/
25	5200	5377	/
26	5400	5577	/
27	5600	5777	TRAIN 2
30	6000	6177	/
31	6200	6377	/
32	6400	6577	/
33	6600	6777	/
34	7000	7177	/
35	7200	7377	/
36	7400	7577	/
37	7600	7777	SAVE AREA FOR RIM/BIN LOADER

Remarks INTERVAL COUNTER MODE IC1 IC2 CCR

Program STAP-8

Page	1st A	last A	Content
0	0	177	ZEROPAGE
1	200	377	SR
2	400	577	SR
3	600	777	SR
4	1000	1177	SR
5	1200	1377	SR
6	1400	1577	SR
7	1600	1777	SR
10	2000	2177	SR
11	2200	2377	CHDSC
12	2400	2577	DSCTBL
13	2600	2777	FLPBUF
14	3000	3177	FLPBUF
15	3200	3377	FLPBUF
16	3400	3577	RESIDENT SEQUENCE STORAGE LOCATION
17	3600	3777	TRAIN 1/2
20	4000	4177	/
21	4200	4377	/
22	4400	4577	/
23	4600	4777	/
24	5000	5177	/
25	5200	5377	/
26	5400	5577	/
27	5600	5777	8-5-S / 8-25-F
30	6000	6177	/
31	6200	6377	/
32	6400	6577	/
33	6600	6777	/
34	7000	7177	/
35	7200	7377	/
36	7400	7577	/
37	7600	7777	SAVE AREA FOR RIM/BIN LOADER

Remarks SINGLE TRAIN ANALYSIS / FLOATING POINT MODE