CONDITIONAL PLOTS FOR NONRENEWAL NEURAL SPIKE TRAIN DATA

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Institute of Statistics Mimeo Series No. 2234

Biomathematics Series No. 38

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KEY WORDS: Point processes, 2-D smoothing, log and cube root transformations

Abstract: *Interspike interval data (times between action potentials) from cat auditory nerve and simulations of such data are examined for serial dependence in several ways that use plots obtained from conditional interval histograms. Following a test for stationarity; the conditional mean, conditional quantiles, conditional standard deviation, and conditional c.v. plots were examined for trends with the conditioning being done on the preceding interspike interval. These plots can be summarized by a conditional box plot. The scatterplots of one interval vs various lagged intervals were examined using contour and perspective plots. For the perspective plots, a gaussian kernel was used with the smoothing parameter determined by the data set size. Since the empirical histograms contained a relatively large positive skew and Pearson plots of conditional moments indicated they were close to a gamma or inverse gaussian distribution, the log and cube root transformations were used on the perspective plots (Hernandez and Johnson, 1980).*

Three data sets are examined in this paper, two from cat auditory nerve and one simulation. The cat auditory nerve spike train data sets were obtained from Dr. Eric Javel of Duke University Medical Center, Durham, N.C. The cat auditory nerve fiber was stimulated by a 417 Hz tone harmonic complex with sound pressure levels (SPL) of 0 or 20 dB (Horst et al., 1986). These two data sets will be referred to as AUD0 and AUD20. Each data set in turn represents two repetitions at a fixed SPL. No major differences in univariate statistics were noted between repetitions in either data set (Liu, 1991). Figure 0 shows the interspike interval histograms for 0 dB (A) and 20 dB (B).

A two-parameter gamma distribution with shape parameter a=1.45 and scale parameter b=9.5was selected for simulating the cat auditory nerve response. These parameters produced matching of the first two moments of AUD0. If a spike train is renewal then its interspike intervals τ_n are independent and identically distributed (iid). Figures 1-6 correspond to the simulated data set CG50A and provide a renewal process benchmark for examining the neurophysiological data.

Figure 1 is a conditional box plot of the simulated data (CG50A). The pairs (τ_n,τ_{n+1}) of the interspike intervals are grouped with respect to the magnitude of the conditioning interval τ_n into 20 equal cell size bins corresponding to consecutive 5 % of the conditioning intervals, i. e., the first cell corresponds to the conditioning intervals τ_n being 0 to 5 percent, for the second the conditioning intervals are from the 5 to 10 %, and so forth. No significant trends are apparent.

The conditional interval histograms of CG50A are shown in figure 2. The conditional interval histograms are a plot of the interspike intervals grouped into 20 equal size cells as in the box plot. If the spike train is renewal, then the conditional interval histograms should be identical to within sampling error. There appears to be no significant differences between histograms, this is consistent with the hypothesis that the spike train is renewal.

A series of eight plots can be used to summarize the conditional interval histograms: the firing rate, serial correlogram, conditional mean, conditional quantiles, conditional standard deviation, conditional c.v., residuals of conditional means, and Pearson plot (Liu, 1991). Figure 3 shows the conditional mean, quantiles, standard deviation, and c.v. respectively. The firing rate plot showed minor fluctuations but no trends. The slope estimate of the conditional mean plot is positive with a significance level higher than 0.05 but not higher than 0.01. No trends can be found in the standard deviation and c.v. plots. These plots also support the hypothesis of a renewal spike train.

Figure 4 is a combination of two plots for data simulating the cat auditory nerve responses (CG50A). The top plot is a scatterplot of the pairs of interspike intervals. A gaussian kernel was used for the conditional density estimation with a smoothing parameter determined by the data set size, n=2000. The smoothing parameter or bandwidth $h=n^{-1/6}$ was obtained by minimizing the integrated expected squared error of the kernel density estimator (Silverman, 1986). The contours are shown on the top scatterplot and the bottom plot is the density surface or perspective plot.

In figure 5 and figure 6 a cube root and a log transformation were selected to transform the simulated data (CG50A) to near normality (Hernandez and Johnson, 1980), since the empirical histograms contained a relatively large positive skew and Pearson plots of conditional moments suggested a gamma or inverse gaussian (Liu, 1991). Each figure of the transformed data has a contour and perspective plot.

Figures 7-12 and 13-18 parallel the plots for CG50A but correspond to the auditory nerve data AUD0 and AUD20, respectively.

Figure 7 is the conditional boxplot of AUD0. In contrast to figure 1, a significant negative trend is now present, but is not apparent due to the large positive skew of the data, c.f. figure 9. The conditional interval histograms of AUD0 are shown in figure 8. Figure 9 is the series of plots used to summarize the conditional interval histograms. The conditional mean plot and correlogram indicate a negative serial dependence, in contrast to figure 3. Since the conditional c.v.'s are rising and the conditional quantiles are approximately parallel, a location shift in the conditional interval histograms is suggested (Liu, 1991; c.f. Johnson et al., 1986).

Figure 10 is the scatterplot with contours and the density surface of AUD0 with n=6202. No apparent periodicities are seen. Figure 11 and figure 12 are the scatterplot and density surface of the transformed data. In figure 12, the perspective plot of AUD0 with a log transformation indicates there is some periodicity in the interspike interval data which is not apparent from the conditional interval histograms or from figure 10. The periodicities seen via the transformations become more apparent at 20 dB, i.e., AUD20.

Figure 13 is the conditional boxplot of AUD20. In figure 14, the conditional interval histograms indicate a scale shift (Liu, 1991). Figure 15 is the series of plots that summarize the conditional interval histograms. The conditional mean plot and correlogram again indicate a negative serial dependence. Since the conditional c.v.'s are flat and the conditional quantiles are not approximately parallel, a scale shift is suggested (Liu, 1991).

Figure 16 is the scatterplot and density surface of AUD20 with n=6749, slight modulations of the perspective plot are apparent. However, in figure 17 and 18, the scatterplot and density surface of the transformed data, the modulations are dramatically shown. In figure 18, the perspective plot of AUD20 with a log transformation indicates that the periodicities have intensified with an increased sound pressure level (SPL) as expected.

In conclusion, the interval histograms of the cat auditory nerve responses (AUD0 and AUD20) showed that the number of observations in the 2-3 msec. bin were larger than expected. The patterns in the perspective plots suggest this peak reflects "phase locking" (nonstationarity due to synchronous firing to the periodic stimulus) and are in marked contrast to the simulated renewal process (CG50A).

The conditional mean plot and correlogram show a negative serial dependence for both data sets, indicating they are not renewal. For AUD0, since the conditional c.v.'s are rising and the conditional quantiles are roughly parallel, a location shift in conditional interval histograms is suggested. However the conditional interval histograms of AUD0 do not totally verify this suggestion. The lack of fit is perhaps due to the phase locking. For AUD20, since the conditional c.v.'s are flat and the conditional quantiles are not parallel, a scale shift in the conditional interval histograms is suggested.

The scatterplot of AUD0 and AUD20 after a log or cube root transformation indicates there is some periodicity in the interspike interval data which is not apparent from the conditional interval histograms nor from the nontransformed scatterplot. These periodicities are more apparent with the higher intensity level (SPL), indicating that these periodicities are a real part of the nerve response, rather than an artifact, e.g., extraneous noise due to heartbeat, etc. The two repetitions making up AUD0 and AUD20 also exhibited this pattern.

In summary, hidden periodicities in cat auditory nerve data may be more easily detected with density surfaces and by using normalizing transformations of the data. (Partial support from ONR grant N00014-90-J-1646)

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Silverman, B. W. (1986), Density Estimation for Statistics and Data Analysis, New York: Chapman & Hall.

Figure Legends

Fig. 0. (A) Histogram of intervals for AUD0. There are 6203 intervals. (B) Histogram of intervals for AUD20. There are 6750 intervals. Binwidth for both plots is 1.0 msec.

Fig. 1. Simulated: Conditional boxplots for simulated gamma renewal process (CG50A). First cell is boxplot for subsequent intervals when conditioning intervals were in lowest 5 percentile of interval data, second cell represents 5-10 percent, etc.

Fig. 2. Simulated: Conditional interval histograms. Each histogram contains 500 intervals. Binwidth is 1.0 msec. Histograms are arranged according to magnitude of conditioning intervals with upper left being smallest and bottom right being largest.

Fig. 3 Simulated: Conditional mean, quantiles, standard deviation, and coef. of variation (cv) plots. The abscissa is the midpoint of the 5% quantile bin of the previous interval, ordinate is statistic of subsequent interval.

Fig. 4. Simulated: Scatterplot with overlaying contours (upper plot) and perspective (lower plot) for consecutive interval pairs (τ_n, τ_{n+1}).

Fig. 5. Simulated: Scatterplot with overlaying contours (upper plot) and perspective (lower plot) for cuberoot transformation of consecutive interval pairs (τ_n, τ_{n+1}).

Fig. 6. Simulated: Scatterplot with overlaying contours (upper plot) and perspective (lower plot) for log transformation of consecutive interval pairs (τ_n, τ_{n+1}).

Fig. 7. AUD0: Conditional boxplots for 0 dB .

Fig. 8. AUD0: Conditional interval histograms. Each histogram contains about 310 intervals and binwidth is 1.0 msec.

Fig. 9. AUD0: Conditional plots for 0 dB.

Fig. 10. AUD0: Scatterplot with overlaying contours (upper plot) and perspective (lower plot) for consecutive interval pairs (τ_n, τ_{n+1}).

Fig. 11. AUD0: Scatterplot with overlaying contours (upper plot) and perspective (lower plot) for cuberoot transformation of consecutive interval pairs (τ_n, τ_{n+1}).

Fig. 12. AUD0: Scatterplot with overlaying contours (upper plot) and perspective (lower plot) for log transformation of consecutive interval pairs (τ_n, τ_{n+1}).

Fig. 13. AUD20: Conditional boxplots for 20 dB.

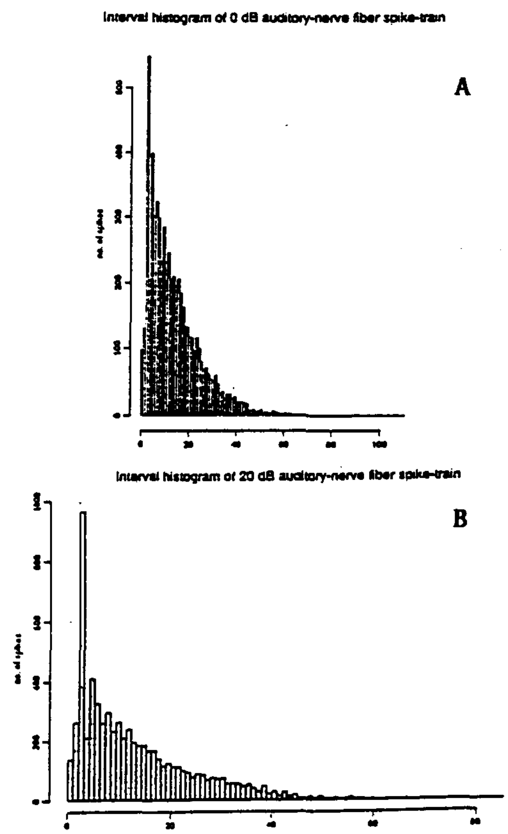
Fig. 14. AUD20: Conditional interval histograms with each histogram containing about 337 intervals and binwidth of 1.0 msec.

Fig. 15. AUD20: Conditional plots for 20 dB.

Fig. 16. AUD20: Scatterplot with overlaying contours (upper plot) and perspective (lower plot) for consecutive interval pairs (τ_n, τ_{n+1}).

Fig. 17. AUD20: Scatterplot with overlaying contours (upper plot) and perspective (lower plot) for cuberoot transformation of consecutive interval pairs (τ_n, τ_{n+1}).

Fig. 18. AUD20: Scatterplot with overlaying contours (upper plot) and perspective (lower plot) for log transformation of consecutive interval pairs (τ_n, τ_{n+1}).



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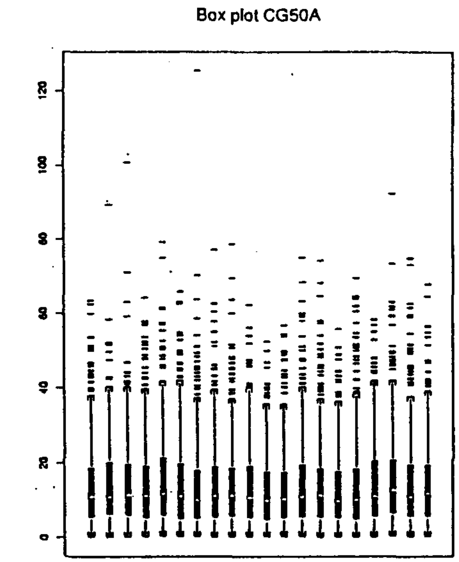
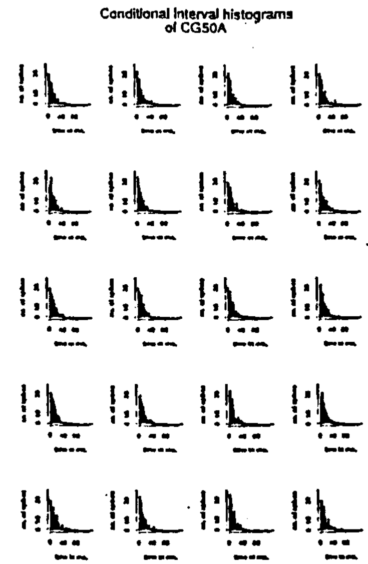
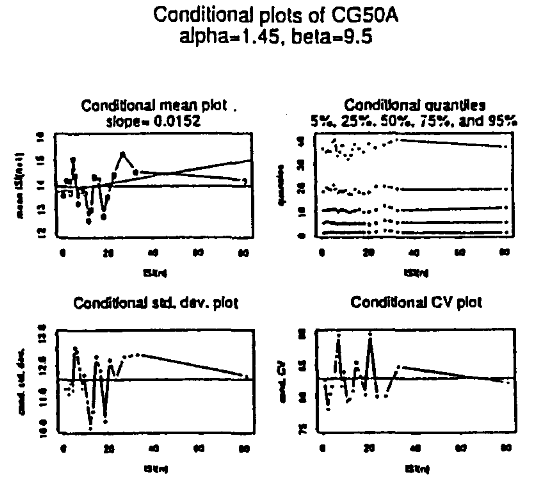

Box plot CG50A

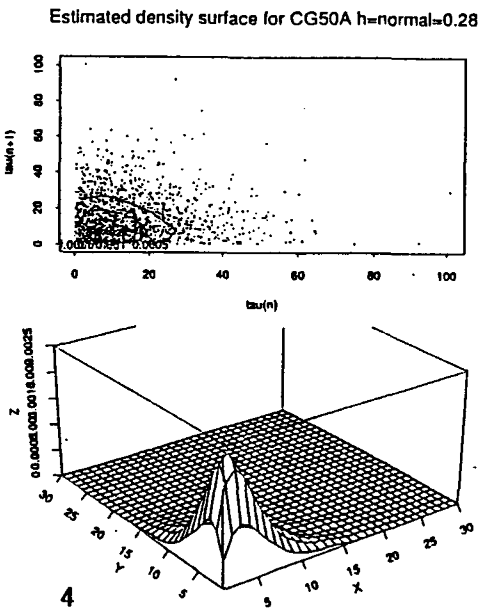
1


Conditional interval histograms
of CG50A

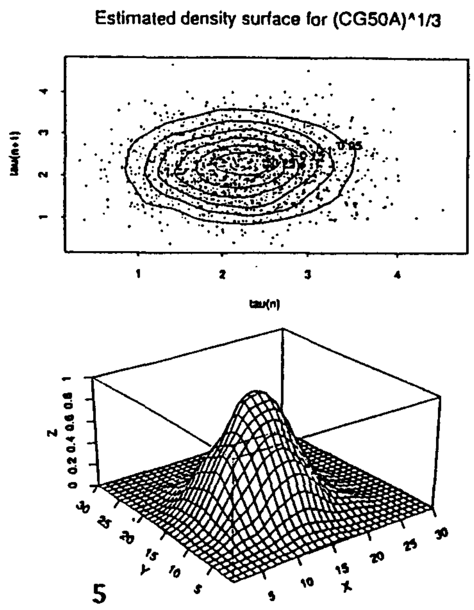
2


Conditional plots of CG50A
alpha=1.45, beta=9.5
Conditional mean plot .
slope= 0.0152
Conditional quantiles
5%, 25%, 50%, 75%, and 95%
Conditional std. dev. plot
Conditional CV plot

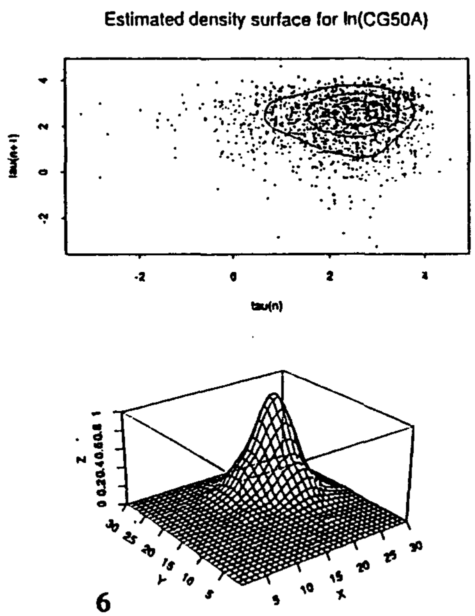
3


Estimated density surface for CG50A h=normal=0.28
tau(n+1)
tau(n)
Z
Y
X

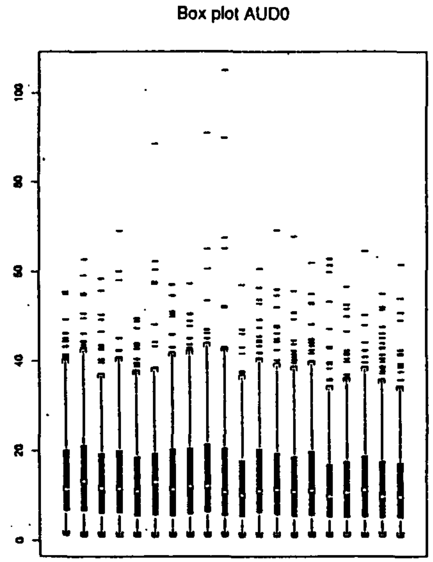
4


Estimated density surface for (CG50A)^1/3
tau(n+1)
tau(n)
Z
Y
X

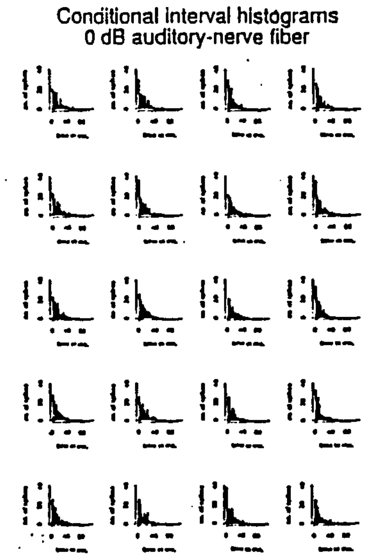
5


Estimated density surface for ln(CG50A)
tau(n+1)
tau(n)
Z
Y
X

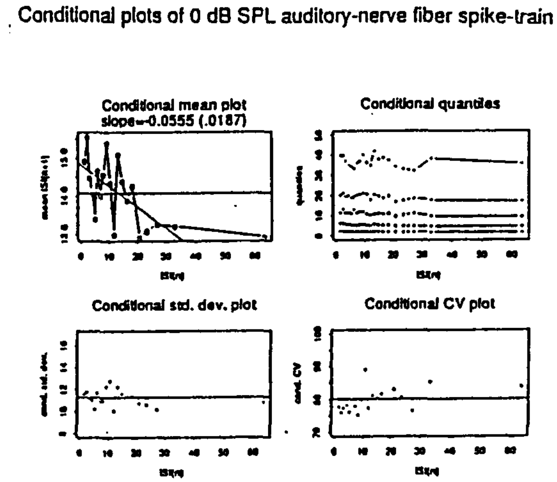
6


Box plot AUD0

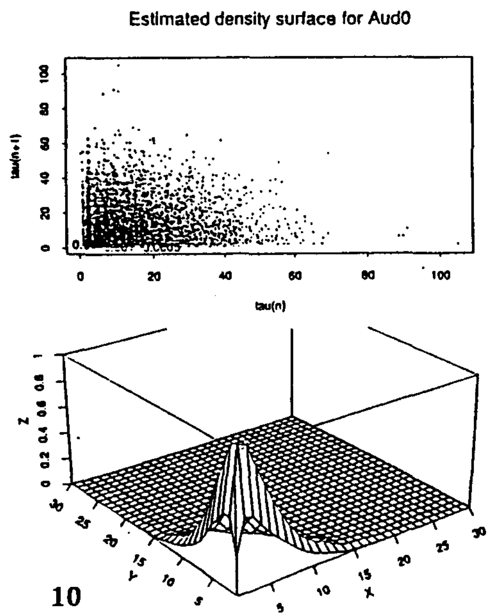
7


Conditional interval histograms
0 dB auditory-nerve fiber

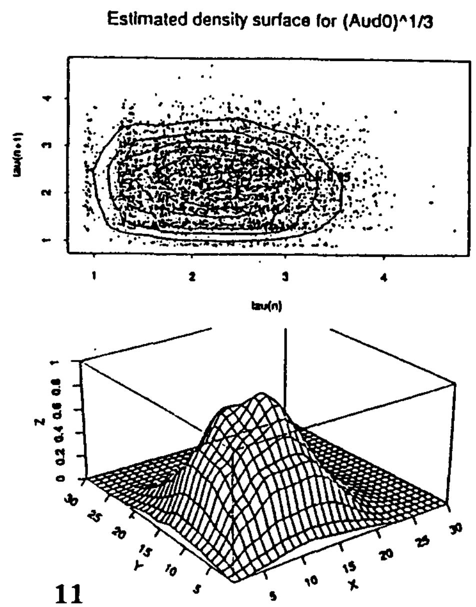
8


Conditional plots of 0 dB SPL auditory-nerve fiber spike-train
Conditional mean plot
slope=-0.0555 (.0187)
Conditional quantiles
Conditional std. dev. plot
Conditional CV plot

9


Estimated density surface for Aud0
tau(n+1)
tau(n)
Z
Y
X

10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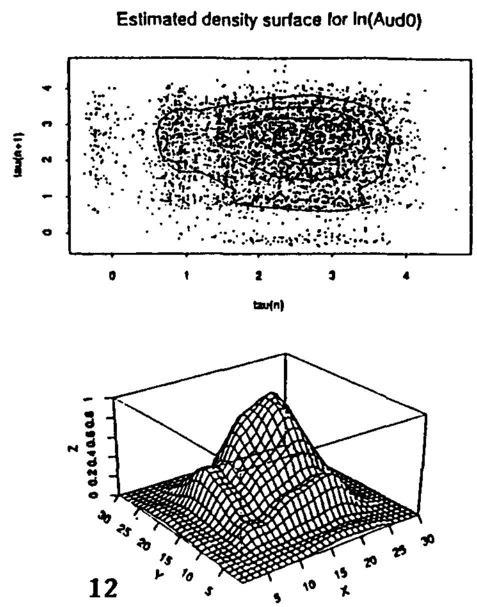
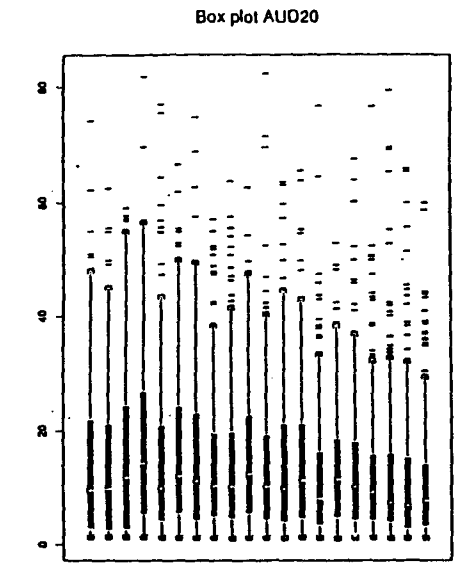
tau(n+1)
tau(n)
Z
Y
X

11


Estimated density surface for ln(Aud0)
tau(n+1)
tau(n)
Z
Y
X

12



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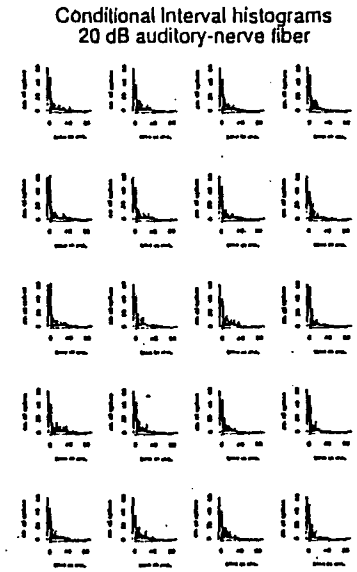

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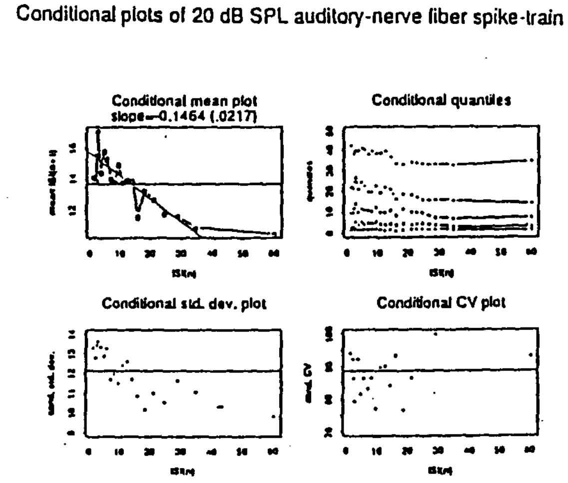

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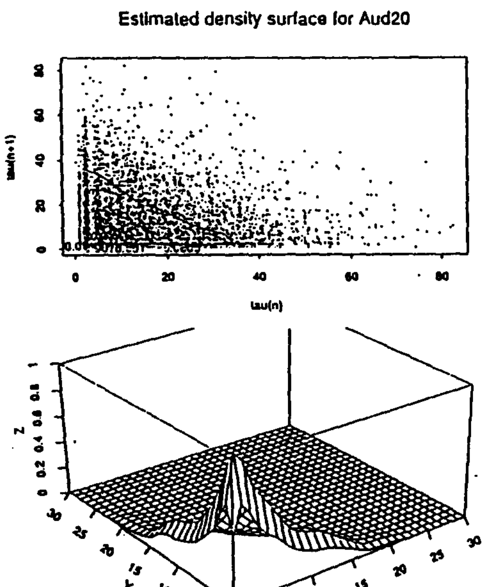

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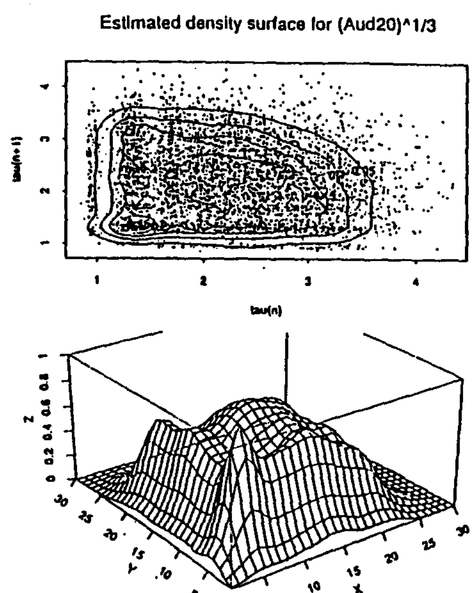

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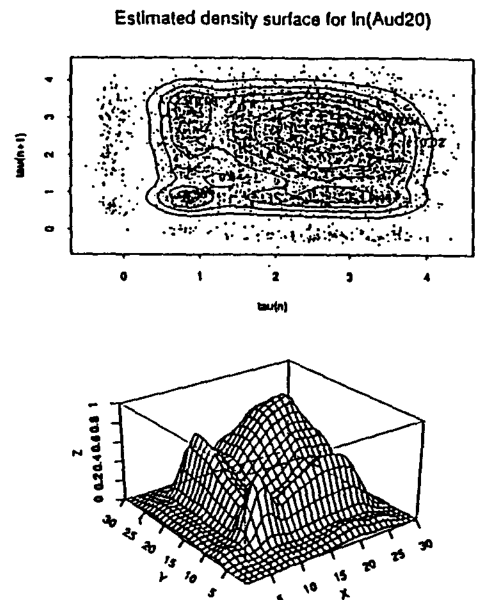

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UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b. RESTRICTIVE MARKINGS:

2a. SECURITY CLASSIFICATION AUTHORITY:

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE:

3. DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public Release: Distribution Unlimited

4. PERFORMING ORGANIZATION REPORT NUMBER(S):

5. MONITORING ORGANIZATION REPORT NUMBER(S):

6a. NAME OF PERFORMING ORGANIZATION: North Carolina State Univ.

6b. OFFICE SYMBOL (If applicable): 4B855

7a. NAME OF MONITORING ORGANIZATION: Office of Naval Research, Department of the Navy

6c. ADDRESS (City, State, and ZIP Code): Dept. of Statistics, Raleigh, North Carolina 27695-8203

7b. ADDRESS (City, State, and ZIP Code): 800 North Quincy Street, Arlington, Virginia 22217-5000

8a. NAME OF FUNDING / SPONSORING ORGANIZATION: Office of Naval Research

8b. OFFICE SYMBOL (If applicable): ONR

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: N00014-90-J-1646-1

8c. ADDRESS (City, State, and ZIP Code): Department of the Navy, 800 North Quincy Street, Arlington, Virginia 22217-5000

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification): Conditional Plots for Nonrenewal Neural Spike Train Data (Unclassified)

12. PERSONAL AUTHOR(S): Barbara Bailey, Chia-yee Jerry Liu, Charles E. Smith

13a. TYPE OF REPORT: TECHNICAL

13b. TIME COVERED: FROM ______ TO ______

14. DATE OF REPORT (Year, Month, Day): September 1992

15. PAGE COUNT: 7

16. SUPPLEMENTARY NOTATION:

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number):

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

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20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL:

22b. TELEPHONE (Include Area Code):

22c. OFFICE SYMBOL: