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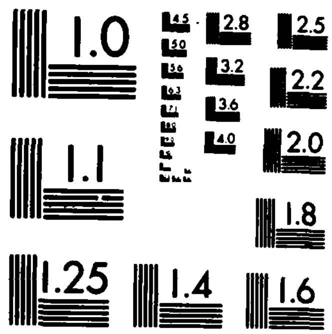
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Two investigators were supported by this grant. ~~Their~~ This research focused on higher order crossings of time series and their application in spectral analysis, and on the various point processes obtained from stationary processes and their relations to reliability models. The higher order crossings theorem was extended to two dimensions, and the one-dimensional version was used to determine the connection between axis crossings and the frequency content of a stationary process. Considerable progress was made in calculating the asymptotic variance-covariance matrix for the vector of higher-order crossing counts, and time series analysis of highly nonlinear and chaotic stationary processes was carried out. The report summarizes progress in these areas.

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INTERIM REPORT ON RESEARCH SUPPORTED BY GRANTS AFOSR-82-0187, B. KEDEM AND E. SLUD principal investigators

The research to be described below is an outgrowth of the original research on higher order crossings carried out by Kedem and Slud (1981, 1982). The research has branched off in two main directions. Dr. Kedem has deepened the research on higher order crossings and their application in spectral analysis while Dr. Slud has emphasized the various point processes obtained from stationary processes and their relations to reliability models. Two students, G. Reed and J. Winnicki, took an active part in the development of this research. The research on higher order crossings is having some impact which, it is hoped, will increase with the publication of some new papers sent for publication. This is particularly so in light of the independent works of Dr. Slud and Mr. Reed on the variances and covariances of higher order crossings which make these quantities more applicable and useful in statistical time series analysis.

The research of Dr. Kedem has concentrated on higher order crossings (HOC) and their applications. To a much lesser degree he also investigated a connection between the Cox model and ARMA modeling.

A significant result obtained by this research is the fact that in the Gaussian case if the first two HOC are equal then the process is a sinusoid w.p. 1. This result is tentatively accepted by the Annals of Statistics and is outlined in TR 82-20, Math. Department, UOM, which was sent to AFOSR. It was later discovered that Roe (1980) characterized the sine function in the deterministic case and in TR83-45, Math. Dept., UOM, we investigate the analogy between the Stochastic (also see Slutsky (1937)) and deterministic cases. (This report will shortly be sent to AFOSR.) A HOC decomposition has been studied in TR 83-14, Math. Department, UOM (sent to AFOSR) and used in the detection of hidden periodicities by means of HOC. We now know precisely the connection between axis crossings and the frequency content of a stationary process. This has been applied successfully to the celebrated Canadian Lynx data. We also found an interesting connection between HOC and periodogram analysis. At present Dr. Kedem is trying to extend his sinusoidal limit in order to develop tests for peak frequencies in stationary time series. At the same time AR-HOC spectral estimates are under study.

Dr. Kedem has extended the HOC Theorem of Kedem and Slud (1981, 1982) to two dimensions in IEEE Information Theory, 1983. This gave rise to the extension of the psi square statistic to texture discrimination which appeared in Proceedings of IPA Conference, Beer Sheva, June 1983.

This research points at a new direction in time series analysis as it incorporates visual features. We would like to think of this approach as being graphical and combinatorial in nature. This is a new idea and some of it has been outlined in 1982 in IEEE PAMI. This last particular work has attracted attention and the Editor, MIT Press, suggested to Dr. Kedem to write a book on this subject. It is felt that such a book is a worthwhile idea provided some more research is carried out.

The HOC Theorem suffers a deficiency in that it does not tell us the rate in which the higher order corssings increase. This problem has been taken up by Dr. Kedem and George Reed (a student who had been supported by our grant for two summers). Under some conditions the rate of increase of the variance of HOC was determined in TR82-43, Math. Department, UOM. Subsequently Mr. Reed proved several more results along the same lines. These results are needed in order to study the distribution of the psi square statistic first advanced in Kedem and Slud (1981, 1982). Mr. Reed in his doctoral dissertation has been able to shed a great deal of light on this fairly difficult technical problem. This thesis is to be defended soon and will be sent as a tech report to AFOSR. We now have a good explanation of the robustness of the psi square statistic. Reed's thesis also deals with second order moments of higher order crossings and in this sense is also related to the recent work of Dr. Slud on this topic.

Extensions of research on HOC to non Gaussian processes was attempted last summer by another student, M. Monsour. The extension to AR models with contaminated error terms seems difficult at present.

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The research of Dr. Slud under this contract has taken three main directions: (i) development of reliability point-process models allowing inter-occurrence times to depend either on the past (this part of the work was joint with J. Winnicki, whose research during the summer of 1982 was also supported by this contract) or on current inter-occurrence times for related point-processes; (ii) numerical computations and simulations with the covariances of higher-order crossing counts for continuous-time Gaussian time series; and (iii) some preliminary work on time series modelling and spectral analysis of certain nonlinear time series (jointly with M. Monsour, a student supported for the summers of 1982-83 under this contract) and of time series related to chaotic dynamical systems (jointly with Professor J. Alexander, a colleague at the University of Maryland).

Dr. Slud's research on reliability point-processes, originally proposed in Section 6 of the initial (Jan. 1982) project proposal, "Statistical Analysis of Events Generated by Time Series," has resulted (a) in a University of Maryland Technical Report "Some Generalizations of the Renewal Process" (joint with J. Winnicki), Maryland Report TR82-65, 1982; and (b) in a paper "Multivariate Dependent Renewal Processes" (1982), submitted to and tentatively accepted by _Advances in Applied Probability_, and also delivered as a contributed paper at the Twelfth Annual Conference on Stochastic Processes and their Applications, July 1983, at Ithaca, New York.

Copies of both of these reports have been sent to the Air Force Office of Scientific Research. It is anticipated that a slight revision of the report with J. Winnicki will be submitted this fall for publication in the Journal of Applied Probability.

In both the initial (Jan. 1982) and follow-up (Jan. 1983) proposals (Section 2 in 1982, Sections 2 and 3 in the part of the 1983 proposal titled "Robustness of Asymptotic Efficiencies in Time Series Analysis"), Dr. Slud outlined a project to catalogue the asymptotic relative efficiencies of the Higher-Order Crossings - based statistics of Kedem and Slud (1981, 1982) versus parametric likelihood-based statistics for various Gaussian time-series. The obstacle to progress in this area has always been the calculation of (asymptotic) variance-covariance matrices for the vector of higher-order crossing counts. Using a new method of proof for a well-known formula (due to Steinberg, Schultheiss, Wogrin and Zweig, 1955, and Crámer and Leadbetter, 1965,1967) for the variance of the number of axis-crossings in the time interval [0,T] for a stationary continuous-time Gaussian process with given covariance function, Dr. Slud has provided new formulas for covariances between numbers of axis-crossings in [0,T] of two jointly stationary Gaussian processes. The methods and results will be documented in a technical report now in preparation, titled "Asymptotic Variances and Relative Efficiencies for Statistics Based on Higher-Order Crossings Counts and Autocorrelations of Stationary Continuous-Time Gaussian Processes, I" (1983).

At the same time, Dr. Slud has programmed and tested two Fortran programs, NUMINT and SIMSER, which respectively perform numerical integrations and simulations to calculate the covariance matrices for higher-order crossings for a large class of continuous-time Gaussian processes. These programs, together with some typical outputs, will be documented in the forthcoming technical report mentioned above. The next stage of research into relative efficiencies of crossings-based versus other time series statistics will make use of the outputs of program NUMINT for a variety of underlying Gaussian processes, following the approach outlined in Section 2 of the 1982 proposal and Sections 2 and 3 of the 1983 continuation-proposal.

Finally, Dr. Slud's research during the current summer (with coworkers M. Monsour and J. Alexander) into the time series analysis of highly nonlinear and chaotic stationary processes, gives an operational aspect to his proposed (Section 4 of 1983 proposal) investigation of mis-specified time series models. At present, Dr. Slud and coworkers have written and tested a package of Fortran subroutines (also implementing the IMSL time-series analysis subroutines) for spectral and residual analyses of nonconventional time series models. In the case of nonlinear time series, the objective of research is to ascertain the robustness and diagnostic value of standard (e.g. Box-Jenkins or spectral) methods of time series analysis on nonlinear-autoregressive time series of the sort discussed by Slud (1982). In the case of time series derived from chaotic dynamical systems, the objective is to recover as much information as possible (from very long records) about the stationarity and ergodic and mixing behavior of some "chaotic" systems known to have very long stretches of transient behavior.

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