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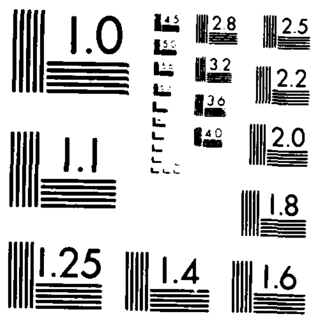

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FINAL REPORT

TO OFFICE OF NAVAL RESEARCH

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ARO DAAG29-80-C-0070

"Multiple Time Series Modeling and Time Series Theoretic Statistical Methods"

Professor Emanuel Parzen, Principal Investigator

May 1983

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This is a final report on the research project entitled "Multiple Time Series Modeling and Time Series Theoretic Statistical Methods" for the period 1 April 1981 - 31 March 1983.

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This final report contains: (1) a list of technical reports which were written on research supported by this project; (2) a list of publications developed from these technical reports, (3) copies of our 1982 and 1983 summary of research program written for the ONR Statistics and Probability Program Summary Report.

Our project on time series analysis has supported collaboration with Professor H. J. Newton (Texas A&M) and Professor Marcello Pagano (Harvard Biostatistics). Its overall goal is to develop algorithms that provide researchers in diverse scientific fields with statistically and computationally efficient techniques for univariate and multivariate time series analysis.

The general ideas and concrete results of the research contributions supported by ONR in this project seem to have had wide impact and applications. Forecasting and spectral analysis (which are among the active problems to which this basic research project has made significant contributions) are statistical procedures of great interest and applicability to many branches of the Defense Department.

Technical Reports Supported by Office of Naval Research

No.; Date	Author(s)	Title
N-21 April 1981	H. J. Newton and Marcello Pagano	The Finite Memory Prediction of Covariance Stationary Time Series
N-22 April 1981	H. Joseph Newton Marcello Pagano	The Cholesky Decomposition Algorithm and ARMA Modeling
N-23 April 1981	H. Joseph Newton Marcello Pagano	A Method for Determining Periods in Time Series
N-24 April 1981	H. Joseph Newton Marcello Pagano	Minimum Mean Square Error Prediction of Autoregressive Moving Average Time Series
N-25 July 1981	H. Joseph Newton	On Some Numerical Properties of ARMA Parameter Estimation Procedures
N-26 July 1981	Emanuel Parzen	Autoregressive Spectral Estimation, Log Spectral Smoothing, and Entropy
N-27 July 1981	Emanuel Parzen	Comments on "The Measurement of Linear Dependence and Feedback Between Multiple Time Series"
N-28 June 1982	Emanuel Parzen	Autoregressive Spectral Estimation
N-29 June 1982	Emanuel Parzen	Autoregressive Spectral Estimation and Functional Inference
N-30 June 1982	Emanuel Parzen	Maximum Entropy Interpretation of Autoregressive Spectral Densities
N-31 June 1982	Emanuel Parzen	Time Series Model Identification, Spectral Estimation, and Functional Inference

Technical Reports Supported by Office of Naval Research (Continued)

No.; Date	Author(s)	Title
N-32 June 1982	H. Joseph Newton	Simultaneous Confidence Bands for Autoregressive Spectra
N-33 July 1982	Herbert T. Davis H. Joseph Newton Marcello Pagano	A Toeplitz Gram-Schmidt Algorithm for Autoregressive Modeling
N-34 October 1982	H. Joseph Newton	Modeling Episodic Time Series
N-35 November 1982	Emanuel Parzen	Time Series Model Identification by Estimating Information
N-36 January 1983	H. Joseph Newton Emanuel Parzen	Forecasting and Time Series Model Types of 111 Economic Time Series
N-37 March 1983	Emanuel Parzen	Time Series ARMA Model Identification by Estimating Information

Publication of Technical Reports

N-21 SIAM Journal of Scientific and Statistical Computing, 4, 1983, pp. 330-339.

N-23 Journal of the American Statistical Association, 78, 1983, pp. 152-157.

N-25 Proceedings of the 13th Symposium on the Interface of Statistics and Computing, ed. W. Eddy, Springer Verlag: New York, 1981.

N-26 IEEE ASSP Workshop on Spectral EstimationI, 1981, ed. S. Haykin.

N-27 Journal of the American Statistical Association, 77, 1982, pp. 320-322.

N-28 Handbook of Statistics III, ed. D. Brillinger and P. Krishnaiah, North Holland: Amsterdam (in press).

N-29 Spectral Analysis and its Use in Underwater Acoustics, International Conference Proceedings, April 1982, London, ed. T. S. Durrani.

N-30 Statistics and Probability Letters, 1, 1982, pp. 2-6.

N-31 Signal Processing in the Ocean Environment Workshop Proceedings, Annapolis, May, 1982, ed. E. J. Wegman (in press).

N-32 Biometrika 1983 (in press).

N-35 Studies in Econometrics, Time Series, and Multivariate Statistics in Honor of T. W. Anderson, ed. S. Karlin, T. Amemiya, L. Goodman, 1983 (in press).

N-36 Major Time Methods and Their Relative Accuracy, by S. Makridakis et al., Wiley: London, 1983 (in press).

N-37 Proceedings of 15th Symposium on the Interface of Computer Science and Statistics, North Holland: Amsterdam, 1984 (in press).

PROJECT TITLE: Multiple Time Series Modeling and Time Series Theoretic Statistical Methods

CONTRACT NO.: N00014-82-MP20001

PRINCIPAL INVESTIGATOR: Distinguished Professor Emanuel Parzen
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LONG RANGE SCIENTIFIC OBJECTIVES: To develop statistically and computationally efficient parameter estimation and model identification techniques for univariate and multivariate time series analysis, and to obtain a unified approach to time series analysis, which serves the needs of each of its diverse fields of application.

PROJECT OBJECTIVES: Time series analysis is regarded as composed of four major problems (model identification, spectral analysis, parameter estimation, and forecasting), which are equivalent in the sense that an answer to any one of these questions generates an answer to the other three questions. These problems must be solved simultaneously, since the "goodness" of model fit, parameter estimates, spectral estimates, and forecasts are essentially inter-dependent, and must employ simultaneously both the time domain and the frequency domain. Spectral estimation techniques provide new functional inference methods of data analysis.

CURRENT STATUS OF THE PROJECT: It is developing approaches for attaining a goal of time series analysis: from a finite sample, identify models which provide efficient forecasts, and efficient estimators of the spectral density which do not introduce spurious spectral peaks, and resolve close spectral peaks.

The proposed approach first determines the memory type of a time series: long, short, or no (white noise). A short memory time series is modeled by an approximating AR, MA, or ARMA scheme. A long memory time series Y(t) is modeled as: (1) a sum of a long memory signal plus a short memory noise, or (2) as the input of a high-pass filter whose output Y(t) is short memory. Approximating autoregressive schemes play two roles: as spectral estimators, and as diagnostic tools for identification of memory type and ARMA type. Model identification criteria are motivated through concepts of estimating information. Measures of information divergence, entropy, and functional inference are being investigated, yielding a new proof of the maximum entropy character of autoregressive density estimators.

SIGNIFICANT ACCOMPLISHMENTS Our research has introduced new concepts into empirical time series analysis, including: CAT, criterion autoregressive transfer function, provides order determining criteria for the orders of approximating autoregressive schemes, developed for both univariate and multivariate time series [see Newton (1982)], and provides a powerful test for white noise; MEMORY (no, short, and long) provides an initial classification to be assigned to a time series which determines our strategy for modeling it [Parzen (1981)]; ARARMA models for long-memory time series which propose that the transformation from long memory to short memory be a best-lag non-stationary autoregression [Parzen (1982)].

[1] Parzen, E. (1981) "Time Series Model Identification and Prediction Variance Horizon," Applied Time Series Analysis II, ed. by D. Findley, Academic Press: New York, 415-447.

[2] Parzen, E. (1982) "ARARMA Models for Time Series Analysis and Forecasting", Journal of Forecasting, Wiley: London, Vol. I, No. 1.

[3] Parzen, E. (1981) Autoregressive Spectral Estimation, Log Spectral Smoothing, and Entropy. IEEE ASSP First Workshop on Spectral Estimation.

[4] Newton, H. Joseph. (1982) Using Periodic Autoregressions for Multiple Spectral Estimation. Technometrics, May.

MULTIPLE TIME SERIES MODELING AND TIME SERIES THEORETIC STATISTICAL METHODS

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Long Range Scientific Objectives: Our research aims to achieve the basic goals of statistical time series analysis, which is to develop statistically efficient and computationally effective methods for: (1) identification of models for univariate and multivariate time series, both Gaussian and non-Gaussian; (2) estimation of their time domain parameters; (3) spectral analysis; (4) forecasting.

Project Objectives: This project seeks to develop, both for theoretical elegance and practical guidance, a comprehensive theory of model identification and spectral estimation which clarifies the role of estimators of various types (non-parametric, kernel, maximum entropy, autoregressive, ARMA, ARIMA, bandlimited extrapolation, cepstral, etc.). This project investigates: (1) the proposition that the key ingredient of such a theory is the notion of memory, (2) definitions of memory, (3) various methods for identification of memory type, (4) various estimators of memory index, (5) analogies with recent research on estimation of density-quantile and quantile functions, and (6) roles of statistical computing in time series analysis in two important ways: (a) to rapidly make available to the broader scientific community new algorithms for time series analysis; (b) to make old theoretical ideas of time series analysis practically useful and to stimulate the integration of old and new techniques of time series analysis.

Current Status of the Project and Recent Significant Accomplishments: To identify models for time series and dynamic systems, information theoretic ideas and approximation theoretic ideas are explored. Models for time series $Y(t)$ can be formulated as hypotheses concerning the information about $Y(t)$ given various bases involving past, current, and future values of $Y(\cdot)$ and related time series $X(\cdot)$. To determine sets of variables that are sufficient to forecast $Y(t)$, and especially to determine an ARMA model for $Y(t)$, an approach is developed which estimates and compares various information increments. We discuss how to non-parametrically estimate the $MA(\infty)$ representation, and use it to form estimators of the many information numbers that one might compare to identify an ARMA model for a univariate time series. We discuss how to estimate an index of regular variation measuring the long memory behavior of the spectral density at zero frequency. We discuss Toeplitz Gram-Schmidt algorithms for autoregressive modeling.

TRN-31 June 1982 Emanuel Parzen Time Series Model Identification, Spectral Estimation, and Functional Inference
TRN-32 June 1982 H. Joseph Newton, Marcello Pagano Simultaneous Confidence Bands for Autoregressive Spectra
TRN-33 July 1982 Herbert T. Davis, H. Joseph Newton, Marcello Pagano A Toeplitz Gram-Schmidt Algorithm for Autoregressive Modeling
TRN-34 October 1982 H. Joseph Newton Modeling Episodic Time Series
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TRN-36 January 1983 H. Joseph Newton, Emanuel Parzen Forecasting and Time Series Model Types of 111 Economic Time Series
TRN-37 March 1983 Emanuel Parzen Time Series ARMA Model Identification By Estimating Information