RADAR/SONAR AND TIME SERIES ANALYSIS
FINAL REPORT

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OFFICE OF NAVAL RESEARCH

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INSTITUTE FOR MATHEMATICS AND ITS APPLICATIONS
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PROGRAMMATIC ITEMS

VIII. SCIENTIFIC DESCRIPTION OF SUMMER 1990 RADAR AND SONAR PROGRAM.

The organizing committee for the program "Radar and Sonar" consisted of: Alberto Grunbaum (chairman), Marvin Bernfeld, Richard E. Blahut, and Richard Tolimieri.

LIST OF ACTIVITIES

The IMA program on Radar and Sonar was a follow-up on a portion of the 1988 IMA summer program on Signal Processing; it included ideas which were suggested by the participants of that program. Our goal was to increase the interaction between mathematicians and electrical engineers in universities and mathematical scientists in industry working on significant problems in radar or sonar.

The first week of the program was tutorial. The second week was devoted to presentations of problems by scientists from industry or universities. The problems we were looking for were those of significance to the field of radar or sonar as well as containing mathematical issues.

Week 1, June 18–June 22, 1990

TUTORIAL

Lecturers: Richard E. Blahut, Willard Miller, Jr. and C.H. Wilcox

The first week was run as a summer school. There were three minicourses, each consisting of five-hours of lectures. Lecture notes prepared by the lecturers were distributed to students and participants they arrived. With the idea of an audience consisting mainly of mathematicians and engineers, the tutorial topics were one on mathematics, one on the physical aspects of scattering, and one on the engineering modelling and processing of the phenomena under consideration.

A great effort was be made to insure that this week was devoted to help people cover two out of the three short courses in detail: a mathematician needed to spend more time and effort in the engineering and physics components, and a corresponding distribution of effort was encouraged for engineers and physicists.

Minicourse 1
lecturer: Willard Miller,Jr.

TOPICS IN HARMONIC ANALYSIS
WITH APPLICATIONS TO RADAR AND SONAR

Minicourse 2
lecturer: C.H. Wilcox

SONAR AND RADAR ECHO STRUCTURE

Minicourse 3
lecturer: Richard E. Blahut

THEORY OF REMOTE SURVEILLANCE ALGORITHMS

Week 2, June 25–June 29, 1990

RESEARCH PROBLEMS

Scientists from industry and government agencies who were working on problems in Radar or Sonar presented research problems. During this week, in addition to the audience of the first week, there were other invited participants (mostly from universities) whose research is connected to Radar and Sonar.

RESEARCH AND TUTORIAL ASSESSMENT

Assessment of the program by Alberto Grunbaum:

From my point of view I consider this effort a complete success. The format consisting of one week of EXTREMELY WELL PREPARED LECTURES, followed by a week of fairly informal talks on (most of the time) open problems is very close to ideal.

I was very impressed by the three lecturers of the first week: they were supposed to deliver to the participants complete lecture notes weeks before the Workshop, and this is exactly what they did. Not only that but the material was completely polished and ready to use as a very good book. The style of lecturing of all three kept the audience tuned in all the time on the three topics: people kept coming back to all of them and there was a nice spirit established that allowed people to ask, interrupt, try to really follow, etc..

I think that everyone got the idea that the most challenging part of the interaction among math people and engineers is one of learning a bit of each others language, so that the trees will not cover the forest.

I did not count very systematically the audience , but I think that we had a core of somewhere between 25 and 35 people coming to all the lectures. This included a present and a former Director of IMA for a good part of the time. And they were among the ones asking questions.

The second week was very different in character. I managed to exercise my dictatorial powers in keeping every speaker to 30 minutes. Next time I would go for 25 and 5 minutes of questions. We did not have a huge number of talks and this really gave people a chance to go back to their offices and try to digest the material. This was particularly true the first week: I spent many nights till 12 pm in my office doing just that, and ran into many other participants working their tails off to understand the material of the day.

I think that the material that we tried to present the first week: 1) some of the basic physics that gives therelation between the "object" and the measured scattered pattern, 2) some of the harmonic analyisis that allows you to understand this "transform" in a mathematical framework, and 3) some of the signal processing issues connected with handling truly discretized and noisy samples of the "ideal" echo, are at the core of the problem .

Personally, I managed to establish contacts with "real people" who will I hope be willing to carry out some experiments in which I am very interested. In fact the lack of a "central place" for more continued interaction of this kind is a troubling point in my mind; I hope that we have made a start, and this crowd can be assembled back sometime soon.

I think we all really worked very hard (in my case only for the two weeks that I was there) and IMA did a splendid job.

RADAR/SONAR, PART I

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RADAR/SONAR, PART II

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EDITORS: M. BERNFELD, R. BLAHUT AND A. GRUNBAUM

*Papers received to date.

IX. SCIENTIFIC DESCRIPTION OF SUMMER TIME SERIES PROGRAM.

The organizing committee for the program "New Directions in Time Series Analysis" consisted of: Emanuel Parzen (chairman), David Brillinger, Murray Rosenblatt, Murad Taqqu, John Geweke and Peter E. Caines.

The theory and methods of time series analysis lie at the intersection of the mathematical, statistical, computational, and system sciences, and provide an elegant interplay among these disciplines. They provide the means of applying advanced mathematical ideas and theorems to contribute towards the solutions of very practical problems. Time series analysis is truly an *interdisciplinary* field, because development of its theory and methods requires *interaction* between the diverse disciplines in which it is being applied. To harness its great potential there must develop a community of statistical and other scientists who are educated and motivated to have a background in theory and methods of time series analysis adequate to handle the problems of time series analysis in *all* the fields in which they occur.

The reasons as to why it was important and timely to conduct an Interdisciplinary Workshop on New Directions in Time Series Analysis in 1990 are:

(1) major advances are occurring in the theory and applications of time series, and they need to be more widely disseminated among time series researchers;

(2) there are many new directions of research, including nonlinear problems, non-Gaussian models, higher order spectra, long-range dependence, random fields;

(3) the methods of time series analysis are of great interest for their potential and actual application in many applied fields;

(4) communication among the community of researchers will be enhanced by bringing theoretical and applied researchers together in the time and space setting provided by the IMA workshop;

(5) the published Proceedings can be expected to be an important stimulus to applications of, and research in, newly developed methods of time series analysis;

(6) there had not been for many years an interdisciplinary workshop in time series analysis; the IMA 1989 Summer Program on Statistics intersected the Time Series Workshop only briefly in our Week III on Statistics.

LIST OF ACTIVITIES

The organizational plan of the workshop was to have theme weeks organized as follows:

Week 1, July 2–6, 1990

NON-LINEAR AND NON-GAUSSIAN MODELS AND PROCESSES

Organizers: David Brillinger and Murray Rosenblatt

Topics included higher-order moments and spectra, bilinear systems, nonlinear processes, applications to astronomy, geophysics, engineering, simulation.

Week 2, July 9–13, 1990

SELF-SIMILAR PROCESSES AND LONG-RANGE DEPENDENCE

Organizer: Murad Taqqu

Topics included time series with long memory self-similar processes, fractals, 1/f noise, stable noise.

Week 3, July 16–20, 1990

INTERACTIONS OF TIME SERIES AND STATISTICS

Organizer: Emanuel Parzen

Topics included time series model identification, analysis of categorical valued time series, nonparametric and semiparametric methods for time series.

Week 4, July 23–27, 1990

TIME SERIES RESEARCH COMMON TO ENGINEERS AND ECONOMISTS

Organizers: John Geweke and Peter Caines

Topics included modeling of multivariate (possibly non-stationary) time series, especially by state space and adaptive methods.

The talks on July 16 were dedicated in honor of John Tukey's contributions in Time Series Analysis.

RESEARCH ASSESSMENT

Assessment by D.R. Brillinger and M. Rosenblatt of Week 1 "Non-linear and non-Gaussian models and processes":

The first week of the Summer Program brought together statisticians, probabilists, engineers and dynamic systems researchers from different countries. The topics dealt with in the first week were broad and yet there was a great deal of interplay between the ideas presented by the operators. There were distinctions between deterministic and stochastic models, between applications and theory, and between various nonlinear models and techniques. The material was current and it seems clear that the proceedings should be of great interest. The spirit was informal with two morning talks and one afternoon each day. This allowed much **ad hoc** discussion to take place between the participants.

Individuals spoke of how important it had been for them to interact in this way with the experts on the different topics.

It is hard to imagine how the environment and facilities provided by the IMA could be improved upon. Particularly important to the applied participants were the office-based computer facilities allowing both in-house computation and direct connection to home facilities.

Assessment by Murad Taqqu of Week 2 of the Time Series Workshop:

The second week was devoted to 'Self-similar processes and long-range dependence." There were many participants from abroad including Canada, Japan, Europe and even the USSR. The week was very successful. It brought together mathematicians, statisticians and engineers, people who do not usually have the opportunity to meet together. Through formal talks and informal discussions, the participants became aware that long-range dependence can arise in diverse settings, that it has its own intrinsic mathematical interest in connection with self-similarity and fractals and that statistical techniques that can detect its presence and estimate its intensity are still inadequate.

Although there had been specialized meetings in the past, this is the first time that such a workshop has taken place. The diversity of the participants' background gave rise to lively discussions, and there were many opportunities for informal discussions.

The talks reflected the diversity of points of view. Some focused on the presence of self-similarity in dynamical systems, on multifractals, scaling in networks and on 1/f noise. Several talks concerned limit theorems under long-range dependence. A number of presentations were devoted to statistical problems for detection and estimation. Benoit Mandelbrot, in addition to a technical presentation of multifractals presented a very interesting video "New York Notes," a show of fractals with accompanying music by Charles Wuorinen.

The IMA environment was particularly suitable for this kind of meeting. The facilities were great and the staff extremely helpful and efficient.

Assessment by Emanuel Parzen of Week III:

As many as 100 people attended many sessions. There were 10 one hour talks, 15 half hour talks, 1 hour of tribute to John Tukey, and 1.5 hours of open forum. The 20 hours of formal meetings provided, and stimulated, ample time for informal discussions. Morning sessions started at 8:30 a.m., afternoon sessions at 1:30 p.m., Coffee breaks at 9:30 a.m. and 2:30 p.m. There was a workshop dinner Thursday evening.

Participants reported that the meeting was the best, most productive, and most enjoyable ("fun") of any meeting that they had ever attended "They never knew they could learn so much so fast".

The proceedings are expected to provide a major reference work, providing a broad survey of past and future research accomplishments in the statistical theory of time series analysis.

Speakers represented almost all senior faculty members in U.S. Statistics Departments who are active in Time Series research. Personal reasons forced the following invited speakers not to attend: Peter Bloomfield, H.L. Gray, Johannes Ledolter, Adrian Raftery, George Tiao, and Robert Kohn from Australia. Ruey Tsay spoke in week IV.

A highlight of week III was the participation of John Tukey, to whose pioneering and fundamental contributions the week was dedicated. Another historic figure whose presence enriched week III was Akiva Yaglom from Moscow.

The success of the workshop was made possible by the support provided by the IMA Director (Avner Friedman), Associate Director (Willard Miller), staff, facilities, and arrangements. All participants expressed their deep appreciation of the outstanding work of the IMA, and of the support of sponsoring agencies.

Assessment by John Geweke of Week IV:

The participants and topics in this portion of the program were representative of problems in time series currently being studied by econometricians. Specific topics addressed, all by more than one participant, included the following.

(1) Inference for possibly nonstationary time series. There was particular focus on testing the unit root hypothesis, with comparisons of Bayesian and frequentist procedures.

(2) Alternatives to unit root models as descriptions of nonstationarity and forecasting devices. In particular, the use of long-memory models was discussed. The focus here was on the substantial technical problems that arise in using likelihood-based methods, and several lacunae in the asymptotic distribution theory.

(3) Nonlinear time series models. There is a wide variety of alternatives to the standard linear model. Two discussed in these sessions were (a) semi-parametric extensions of the widely used autoregressive conditional heteroscedasticity (ARCH) model and (b) chaotic models.

(4) Model based inference using a multitude of time series. While much of econometric time series work is similar to what is done in statistics or engineering, much of it is also distinguished by the available of well-specified models grounded in economic theory. This poses special problems for inference, in that likelihood functions are typically highly nonlinear in the parameters. When longitudinal data bases are employed, data base management becomes an additional feature of the problem.

Much of the informal discussion, among the econometricians and together with the engineers, focussed on the validity and usefulness of classical stochastic model specification; and conditional on the validity and usefulness of this approach, the relative merits of Bayesian and frequentist methods, both in principal and in practice. Needless to say these issues were not resolved with any finality in one week. However, all participants gained insights.

at the technical level, into approaches different than the ones conventional in their discipline. The key interactions here occurred between the systems theorists in engineering and econmetricians grounded in statistics; and between the Bayesians and frequentists among those with a statistical background.

Assessment by P. E .Caines of Week IV:

The overall purpose of the engineering section of the IMA Time Series Meeting was to present current directions of research in stochastic systems for the purposes of modeling, prediction and control. The engineering sessions were alternated with the econometric sessions in order to maximize the probability of cross-fertilization between the fields. In particular, at the suggestion of Manfred Deistler, an open forum on common issues in engineering and econometrics was held during the lunch period on the Thursday.

A summary of the activities in the engineering section is as follows (co-authors of papers are given in the complete listing of the programme and in the proceedings): The Monday afternoon session was focussed on the questions of structural issues in the construction of dynamical mathematical models for observed processes. The speakers here were: Cornelis Los (A Scientific View of Economic Data Analysis), Ben Hanzon (Parameter-Independent Characterizations of the Structure of a Linear Dynamical Model), Anders Lindquist (Stochastic Realization Theory) and Andrea Gombani (Approximate Stochastic Realizations).

The following morning the talks centered on the problem of estimating exact and approximate structures of linear systems. In this session issues of stochastic complexity, and the geometric and topological properties of realizations of linear systems were addressed. These ideas were then considered in the analysis of the properties of estimators for such important quantities as the order(s) of a system in ARMAX form. Specifically the talks were: Laszlo Gerencser (Stochastic Complexity and Modelling), C Z Wei (Recursive Estimators and Oder Estimation Criteria) and Jan Maciejowski (Balanced Realizations, Linear Systems and Identification).

The next topic on the engineering agenda was stochastic adaptive control. This may be viewed as the application of recursive identification to the problem of the stabilization and performance enhancement of a system whose dynamics -in particular parameters – are a priori unknown and which must be learned in "real time". One of the main outstanding problem areas is the adaptive control of systems whose dynamics are changing in time. The speakers in the session on the adaptive control of time varying systems were: Sean Meyn (Estimation and Control of Time Varying Systems: A Markov Chain Analysis of Stability and Performance), Peter Caines (Controllability and Ergodicity of Jump Parameter Adaptive Control Systems), Ren Wei (The Convergence of Parallel Model Adaptation Schemes in the Presence of Colored Noise), Han-Fu Chen (Convergence of the Astrom-Witternmark Self-Tuning Regulator and Related Topics) and Lei Guo (Identification and Adaptive Control for Time-Varying Stochastic Systems).

The talks the following morning returned to the themes of structural properties of linear system models and the fundamental issues of constructing models for data.In this view the set of possible trajectories of the data is the system to be estimated. This talk was given by Jan Willems (Continuity of Latent Variable Models).

The subsequent talk presented an approach to the time varying system model problem which connected to the previous talks on system oder estimation, maximum likelihood techniques and complexity measures for system models. The term "smoothness" in the title refers to dynamical properties of the hypothesized models for the evolution of the signal or the dynamical model itself: Will Gersch (Smoothness Priors).

The subsequent talk addressed the errors in variables problem introduced earlier by Cornelis Los and presented results concerning the identifiability of dynamic models of this type: Manfred Deistler (Identification of Dynamic Systems from Noisy Data).

Following the talk of Manfred Deistler the topic of recursive estimation and control of linear systems was treated by T. Z. Lai (Properties of Recursive Estimators in Adaptive Estimation and Control).

T.Z. Lai presented a survey of the properties of the main recursive estimation methods and presented results on the achievment of efficiency by modifications of the algorithms in certain systematic ways. Finally, the engineering section concluded with a survey of the principle results in bilinear modeling, prediction and estimation together with a set of new results: Dominique Guegan (Identification and Forecasting in Non-linear Stochastic Processes).

NEW DIRECTIONS IN TIME SERIES ANALYSIS

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EDITORS: DAVID BRILLINGER, PETER CAINES, JOHN GEWEKE, EMANUEL PARZEN, MURRAY ROSENBLATT, MURAD TAQQU

*Papers received to date.

APPENDIX A: PROGRAM FOR RADAR/SONAR.

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IMA Summer Program

RADAR AND SONAR

June 18 - June 29, 1990

Organizing Committee: Alberto Grunbaum (chairman), Marvin Bernfeld
Richard E. Blahut, Richard Tolimieri

Most of the program talks will be held in Conference Hall 3-180 on the entry floor of the new Electrical Engineering/Computer Science Building. This building is located on the corner of Washington Avenue and Union Street, a block from the IMA Main Office. The conference hall is on the Ethernet and has a projection system for display of computer output.

Week 1, June 18–June 22, 1990

TUTORIAL

Lecturers: Richard E. Blahut, Willard Miller, Jr. and C.H. Wilcox

The first week will be run as a *summer school. There will be three minicourses, each consisting* of five-hours lectures. Lecture notes prepared by the lecturers will be distributed to students and participants. With the idea of an audience consisting mainly of mathematicians and engineers, the tutorial topics will be one on mathematics, one on the physical aspects of scattering, and one on the engineering modelling and processing of the phenomena under consideration.

A great effort will be made to insure that this week will be devoted to help people cover two out of the three short courses in detail: we anticipate that a mathematician will need to spend more time and effort in the engineering and physics components, and a corresponding distribution of effort will be encouraged for engineers and physicists. We will make sure that time is allowed for private study. We will also arrange for discussion sessions where people with different backgrounds will hopefully help each other, and learn in the process a bit about each others language. We consider this last point one of the main goals of this effort.

Minicourse 1
lecturer: Willard Miller,Jr.

TOPICS IN HARMONIC ANALYSIS WITH APPLICATIONS TO RADAR AND SONAR

Abstract: This minicourse is an introduction to basic concepts and tools in group representation theory, both commutative and noncommutative, that are fundamental for the analysis of radar and sonar imaging. Several symmetry groups of physical interest will be studied (circle, line, rotation, $ax+b$, Heisenberg, etc.) together with their associated transforms and representation theories (DFT, Fourier transform, expansions in spherical harmonics, wavelets, etc.). Through the unifying concepts of group representation theory, familiar tools for commutative groups, such as the Fourier transform on the line, extend to transforms for the noncommutative groups which arise in radar-sonar.

The insight and results obtained will be related directly to objects of interest in radar-sonar, such as the ambiguity function. The material will be presented with many examples and should be easily comprehensible by engineers and physicists, as well as mathematicians.

Minicourse 2
lecturer: C.H. Wilcox

SONAR AND RADAR ECHO STRUCTURE

Abstract: The structure of pulse mode sonar and radar echoes is derived from the underlying field equations of fluid dynamics and electromagnetics, respectively. The scattering object Γ is assumed to lie in the far field of both the transmitter and the receiver. In this approximation, the sonar or radar pulse mode signals are shown to be represented by plane waves $s(x \cdot \theta_0 - t)$ at all points x near Γ and times $t \in R$. In the derivation of this result the signal speed is normalized to unity and θ_0 denotes a unit vector which is directed from the transmitter toward Γ. For a stationary scatterer Γ the echoes are also represented by plane waves $e(x \cdot \theta - t, \theta, \theta_0)$ at all points x near the receiver, where θ is a unit vector which is directed from Γ toward the receiver. The principal result of these lectures is the relation

$$e(\tau, \theta, \theta_0) = Re\left\{\int_0^\infty e^{i\tau\omega} T(\omega\theta, \omega\theta_0)\hat{s}(\omega)d\omega\right\}$$

where $\hat{s}(\omega)$ is the Fourier transform of $s(\tau)$ and $T(\omega\theta, \omega\theta_0)$ is the scattering amplitude for Γ. Thus $T(\omega\theta, \omega\theta_0)$ is the amplitude of the scattered field in the direction θ due to the scattering by Γ of a plane wave $e^{i\omega\theta_0 \cdot x}$ with frequency ω and propagation direction θ_0. For scatterers Γ that move with velocity v such that $|v| < 1$ it is shown that the echo waveform is given by

$$e(\tau, \theta, \theta_0) = \frac{\gamma}{\gamma_0} Re\left\{\int_0^\infty e^{i\tau\omega} T(\omega\gamma\theta', \omega\gamma\theta_0')\hat{s}(\frac{\gamma}{\gamma_0}\omega)d\omega\right\},$$

where

$$\gamma = \frac{1 - v \cdot \theta}{\sqrt{1 - v^2}}, \quad \gamma_0 = \frac{1 - v \cdot \theta_0}{\sqrt{1 - v^2}}$$

and θ', θ_0' are related to θ, θ_0 by a Lorentz transformation based on v. Finally, it is known that the high frequency limit

$$\lim_{\omega \to \infty} T(\omega\theta, \omega\theta_0) = T^\infty(\theta, \theta_0)$$

exists. Hence if $\hat{s}(\omega)$ is concentrated in a high frequency band where $T(\omega\theta, \omega\theta_0)$ is essentially constant then one has the approximation

$$e(\tau, \theta, \theta_0) = T^\infty(\theta', \theta_0')s(\frac{\gamma_0}{\gamma}\tau).$$

Minicourse 3
lecturer: Richard E. Blahut

THEORY OF REMOTE SURVEILLANCE ALGORITHMS

Abstract: Algorithms for remote surveillance imaging have been developed independently in many fields including radar, sonar, medical imaging, and radio astronomy. Recently, it has become apparent that an underlying theory of remote surveillance could be developed. This emerging unified theory may suggest new directions for future developments.

This course will develop, from the engineer's point of view the two-dimensional Fourier transform, the ambiguity function, the Radon transform, and the projection-slice theorem. The course will explain how these topics deal with the imaging problem by discussing how they relate to doppler frequency shifts, synthetic aperture radar, and tomographic reconstruction of images. The course will be organized in a way to integrate the vocabulary and methods of the fields of radar, sonar, tomography, radio astronomy, and related fields.

Monday, June 18

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:00 am	Registration and coffee	Reception Room EE/CS 3-176

9:30 am	**Willard Miller,Jr.** IMA	Harmonic analysis with applications to radar, I

bstract: The Doppler effect: wideband and narrow-band ambiguity functions. A group theory primer: thogonality relations for finite group representations. Linear Lie groups.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Calvin H. Wilcox** University of Utah	Sonar and radar echo structure, I

Abstract: Physical principles of acoustics. Sonar pulses with prescribed sources. Sonar pulses with prescribed radiaiton patters. the structure of CW (=Continuous Wave) mode sonar echoes. The CW mode scattering amplitude.

2:00 pm	**Richard E. Blahut** IBM	Theory of remote surveillance algorithms, I

Abstract: Signals in One and Two Dimensions. Pulse Trains. Dirichlet Functions. Pulse Shape Parameters. Fourier Transforms. Rectangular and Hexagonal Sampling. Projection-Slice Theorem. Radon Transform. X-ray Transform. Inverse Radon Transform.

4:00 pm	**Vincent Hall 502** (The IMA Lounge)	IMA Tea (and more!)

Tuesday, June 19

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:15 am	**Coffee break**	Reception Room EE/CS 3-176
9:30 am	**Willard Miller,Jr.** IMA	Harmonic analysis with applications to radar, II

Abstract: Representation theory for infinite groups: orthogonality relations for compact Lie groups, the rotation group and spherical harmonics, Fourier transforms and their relation to Fourier series. Representations of the Heisenberg group: the Schrödinger representation, orthogonality of radar cross ambiguity functions, the Heisenberg commutation relations and the Bargmann-Segal Hilbert space.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Calvin H. Wilcox** University of Utah	Sonar and radar echo structure, II

Abstract: The structure of pulse mode sonar echoes from stationary scatterers. Sonar echoes in the far field. Role of the scattering amplitude. Echoes of high frequency pulses.

2:00 pm	**Richard E. Blahut** IBM	Theory of remote surveillance algorithms, II

Abstract: Ambiguity Functions. Properties. Shape, Resolution and Ambiguity. Ambiguity Function of Pulse Trains. Chirp Pulses. Uncertainty Ellipse. Cross-Ambiguity Function. Computation of Ambiguity Functions.

Wednesday, June 20

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:15 am	**Coffee Break**	Reception Room EE/CS 3-176

9:30 am	**Willard Miller,Jr.** IMA	Harmonic analysis with applications to radar, III

Abstract: More representations of the Heisenberg group: the lattice representation, functions of positive type. Representations of the affine group: the wideband cross ambiguity functions, decomposition of the regular representation.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Calvin H. Wilcox** University of Utah	Sonar and radar echo structure, III

Abstract: Sonar pulse scattering from moving objects. Use of the Lorentz transformation. Structure of the sonar echo wave form. Doppler shift and pulse distortion. Echoes of high frequency pulses.

2:00 pm	**Richard E. Blahut** IBM	Theory of remote surveillance algorithms, III

Abstract: **Antenna Systems.** Antenna Aperture and Pattern. Antenna Gain. Rectangular and Hexagonal arrays. Phased arrays. Interferometry. The Radar Range Equation, Crystallography. Indirect and Direct Methods.

Thursday, June 21

Unless otherwise indicated, the talks today are in Conference Hall EE/CS 3-180

9:15 am	**Coffee Break**	Reception Room EE/CS 3-176
9:30 am	**Willard Miller,Jr.** IMA	Harmonic analysis with applications to radar, IV

Abstract: Weyl-Heisenberg frames: the Weil-Brezin-Zak transform, windowed transforms and ambiguity functions, frames. Affine frames and wavelets.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Calvin H. Wilcox** University of Utah	Sonar and radar echo structure, IV

Abstract: Physical principles of electromagnetic theory. Radar pulses with prescribed sources. Radar pulses with prescribed radiation patterns. The structure of CW mode radar echoes. The CW mode matrix scattering amplitude.

2:00 pm	**Richard E. Blahut** IBM	Theory of remote surveillance algorithms, IV

Abstract: **Radar Systems.** Doppler and Delay. Radar Cross Section, Radar Imaging Systems, The Imaging Equation, Synthetic Aperture Imaging, swath and Spotlight. Bistatic Radar. Radar Astronomy. Interferometry. Detection Threshold. Probability of Detection and False Alarm. Clutter. Moving Target Detection. Cramer-Rao Bounds.

Friday, June 22

Unless otherwise indicated, the talks today are in Conference Hall EE/CS 3-180

9:15 am	**Coffee Break**	Reception Room EE/CS 3-176

9:30 am	**Willard Miller,Jr.** IMA	Harmonic analysis with applications to radar, V

Abstract: The Schrödinger group: automorphisms of the Heisenberg group, Theta functions and the lattice Hilbert space.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Calvin H. Wilcox** University of Utah	Sonar and radar echo structure, V

Abstract: The structure of pulse mode radar echoes from stationary scatterers. Radar echoes in the far field. Role of the scattering amplitude. Radar pulse scattering from moving objects. Use of the Lorentz transformation. Structure of the radar echo wave form.

2:00 pm	**Richard E. Blahut** IBM	Theory of remote surveillance algorithms, V

Abstract: Image Reconstruction and Passive Systems. Tomography. The Radon Transform. Radar Tomography. Phase Contrast Imaging. Radio Astronomy. Passive Detection.

Week 2, June 25–June 29, 1990

RESEARCH PROBLEMS

Scientists from industry, government agencies and universities who are working on problems in Radar or Sonar will present research problems. We expect that a number of new problems and solutions will be generated during the program, and the schedule will remain flexible to allow for last minute changes. During this week, in addition to the audience of the first week, there will be other invited participants (mostly from universities) whose research is connected to Radar and Sonar.

Monday, June 25

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:00 am	**Registration and coffee**	Reception Room EE/CS 3-176
9:30 am	**Marvin Bernfeld** Raytheon	On the alternatives for imaging rotational targets

Abstract: The point-to-point variations in microwave reflectivity (or point reflectivity) of rigid targets normally renders topographical discriminants that are useful in recognizing the different classes. The task of constructing a point reflectivity image, based on backscatter radar measurements, is a problem in inverse electromagnetic scattering and the subject of this paper. When an apparent rotation is introduced into the radar-target model, the reconstruction procedure that is usually specified involves a synthetic aperture radar (SAR) to enhance the resolution of crossrange target features.

In classical SAR systems, the backscattered signals are stored in memory on a rectangular grid and then processed to provide a representation of the desired image over range and Doppler coordinates. This rectangular processing format, however, imposes a severe restriction on the signal processing aperture since the time span that the backscatter can be effectively integrated is limited because of range migration and continuously diminishing Doppler coherence. As a result, the crossrange resolution and the processing gain are often less than desired when classical SAR systems are employed for imaging rotational targets.

The limitation of the classical SAR systems has led to the invention of two additional SAR solutions. One of these has been called CHIRP Doppler Radar and it is currently being evaluated. By employing parallel tomographic measurements involving multiple ridge-like ambiguity functions, which are characteristic of different linear FM slopes, faster measurements are theoretically possible. Therefore, the migration of scatterers through resolution cells, which limits the effective coherent integration of backscatter in the classical SAR systems, can be alleviated. Theoretically, when it is developed, this radar will provide enhanced range-Doppler images compared to the classical SAR systems.

In the second of these solutions, the backscattered signals returned from individual linear FM pulses are stored in polar format after appropriately being processed in a way that yields the radial profiles on the Fourier transform of the point reflectivity. The images are derived, subsequently, by computing the inverse Fourier transform.

The latter solution has already been described by several authors, drawing on an anology, in some cases, to tomographic mathematical methods. This paper also offers a description. The purpose is to provide the background for - it is believed - a new observation concerning the nature of the backscattered signals. Specifically, evidence of the CHIRP-Z transform is observed in the description of the backscattered signals. This is an important observation since it reveals a procedure for reconstructing point reflectivity without resorting to an approximation of backscattered signals that has previously been proposed.

10:00 am	**Walter Schempp** Universitat Siegeu, West Germany	Quantum holography

Abstract: The development of more powerful computers in recent years has been driven by a seemingly unending thirst for automation, control issues, information availability, and a yearning for new understanding of the self-organization principles of ourselves and our environment. The challenges of the future force us to create and study new concepts of adaptive information processing and to implement novel computer architecture based on synergetic principles.

Until now, the increased power has been driven largely by advancements in microelectronics, such as electronic switches (transistors) with higher switching speeds and integrated circuits (ICs) with increased levels of integration. Although the advancements in the IC hardwiring and packaging functions have been significant, their prospect for continuing at the same steady rate are being dimmed by physical limitations associated with further miniaturization.

As a result, computer architects are turning to the design of parallel processors to continue the drive toward more powerful computers. The system of interconnects by which the processing elements can share information among themselves is one of the most important characteristics of any parallel computer. The massively *parallel organization principles* which distinguish analog neural networks from the small scale interconnection architectures of standard digital computer hardware are some of the main reasons for the largely emerging interest in neurocomputers.

Until recently optical computing was looked upon as an alternative technology for performing an old task. Now, a paradigm shift is coming about as a result of the realization that optical computers are fundamentally different from, and in many senses superior to, any electronic computer. Certain optical neurocomputer architectures which are based on the holographic image encoding and decoding procedures are the only available ones that are intrinsically quantum mechanical processors.

The survey lecture presents an introduction to optical and optoelectronic implementations of analog and digital neurocomputer architectures. It deals with the mathematical modelling by the Kirillov quantization procedure of quantum parallelism, according to which different alternative at the quantum level are allowed to coexist in quantum linear superposition. Since quantum effects can occur over distances of kilometers or even light years, the Kirillov quantization allows to study, as a particularly important example, the optical processing of synthetic aperture radar (SAR) data. The quantum mechanical computer approach gives also rise to amacronic structures with applications in imaging systems with processing right at the focal plane similar to the amacrine clustered processing layers in front of the retina.

References

W. Schempp: Harmonic analysis on the Heisenberg nilpotent Lie group, with applications to signal theory. Pitman Research Notes in Math., Vol. 147, Longman Scientific and Technical, Harlow, Essex, and J. Wiley & Sons, New York 1986

W. Schempp: Neurocomputer architectures. Results in Math. 16, 345–382 (1989)

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**P. Moulin** Washington University	A sieve-constrained maximum-likelihood method for target imaging

Abstract: We consider rotating targets having a diffuse reflectance-process. The image to be formed is the two-dimensional power spectrum, called the scattering function, of the reflectance process. Additive receiver-noise is incorporated in the model as well. Statistical estimation theory is used to form the image.

Under this model, the estimation approach is derived by application of fundamental principles of statistical inference. The solution to the stochastic inverse-problem is obtained by application of the principle of maximum likelihood. A fundamental problem that arises is that the parameter space is infinite-dimensional whereas the dataset is finite, so the inverse problem is ill-posed, and regularization of the estimates is needed. We investigate Grenander's method of sieves to address this issue and present two main results. The first is a criterion for selecting the mesh size of the sieve, which determines the rate of convergence of the estimates. This criterion is based on information concepts for measuring convergence in the parameter set and is applicable to a wide class of estimation problems.

In the second part of our study, we recommend a method of sieves based upon a spline representation for the image. Images can be produced at different resolution levels consistent with the dataset and the statistical model. They offer a potential for significant improvements over images obtained via conventional radar techniques. Finally, we propose tractable estimation algorithms for practical applications.
Joint work with J. A. O'Sullivan, and D. L. Snyder.

11:30 am	**Robert Shore** Hanscom Air Force Base	Some problems in obtaining and using incremental diffraction coefficients

Abstract: Incremental difraction coefficients provide an important technique for enhancing the accuracy of the physical optics (PO) approximation. The PO approximation, widely used for calculating scattering from perfectly electrically conducting bodies, consists of approximating the actual currents at a surface point, by those induced on an infinite perfectly conducting plane tangent to the body at the point. The PO approximation works well away from shadow boundaries provided that the radii of curvature of the reflecting surface are large compared with the wavelength, and that there are no surface discontinuties. When surface discontinuties or shadow boundaries are present, the accuracy of the scattered fields obtained via the PO approximation can be significantly improved if the fields radiated by the nonuniform currents (the *difference between the actual and PO currents*) can be closely approximated and included in the scattering calculations. The far-field contribution from the nonuniform current of a differential element of an edge or shadow boundary – the incremental diffraction coefficient (IDC) – can be obtained by regarding the edge or shadow boundary locally as the edge or shadow boundary of a canonical scatterer (e.g., wedge, half-plane, cylinder) provided that an expression is available for the IDC of the canonical scatterer. The IDC can then be integrated along the edges or shadow boundaries to obtain the far field of the nonuniform currents. When IDC's can be found they provide a powerful technique for augmenting the accuracy of the fields calculated using the PO approximation. In contrast to other techniques commonly employed to account for scattering from edge discontinuties of perfectly conducting surfaces (e.g., GTD, PTD), the integration of IDC's along edge discontinuities yields corrections to PO fields that are valid in virtually all ranges of pattern angles, and so avoids having to employ several distinct formulations, each valid in a particular range.

In this paper after a brief introduction to IDC's we first describe a recent and highly useful method for obtaining IDC's for an important class of canonical scatterers. If a closed form expression can be supplied for the scattered far field of a two-dimensional planar scatterer, the IDC's at arbitrary angles of incidence and scattering can be found immediately through direct substitution in general expressions. No integration, differentiation, or specific knowledge of the currents is required. The direct substitution method for determining IDC's is, however, limited to perfectly conducting scatterers that consist of planar surfaces, such as te wedge, the slit in an infinite plane, the strip, parallel or skewed planes, polygonal cylinders, or any combination therof; and requires a closed-form expression (whether exact or approximate) for the two-dimensional scattered far field produced by the current on each different plane of the canonical scatterer.

We then demonstrate the utility of IDC's by presenting a few applications to scattering problems, showing the importance of the nonuniform current contribution to the scattered fields. Examples are shown for the calculation of reflector antenna patterns, and for the calculation of the field scattered by a perfectly conducting circular disk illuminated by a plane wave.

Finally, as an invitation to further work in this area, we draw attention to the importance of removing the restriction of the substitution method for obtaining IDC's to planar, perfectly conducting scatterers. It would

be of much utility if a simple method not involving current integration could be found for obtaining IDC's for a circular cylinder or a rounded wedge (parabolic cylinder), or for non-perfectly conducting scatterers. In addition, the attractiveness of using IDC's for calculating scattering from perfectly conducting scatterers with discontinuities that can be locally modeled by planar canonical scatterers would be considerably enhanced if a general purpose computer program could be developed for such scatterers that would circumvent the currently rather laborious procedure of transforming from the local coordinate system of the IDC's to the global coordinate system of the scatterer in order to integrate the IDC's.
Joint work with Arthur D. Yaghjian.

2:00 pm	**Mireille F. Levy** Rutherford Appleton Lab.	Parabolic equation models for assessment of propagation effects on radar performance

Abstract: Strong refractive index gradients in the troposphere are not uncommon, and have a noticeable effect on radar performance for propagation close to the horizontal. In anomalous propagation conditions, coverage diagrams are distorted, with regions of enhanced propagation and radar "holes". We review these effects, and describe an efficient numerical method based on the parabolic approximation of the wave equation, which allows the computation of the electromagnetic field for propagation in an inhomogeneous atmosphere over irregular terrain.

2:30 pm	**F. Alberto Grunbaum** UC Berkeley	Concentrating a scatterer and its scattering amplitude (or trying to beat Heisenberg)

Abstract: The scattering of a plane wave either by an object or by a potential leads to the notion of the "scattering amplitude". This is a function of the incoming direction, the outgoing direction and the wave number k. There is a complicated nonlinear relation between the shape of the object, or the potential, and this scattering amplitude.

This "scattering transform" enjoys many of the properties of the Fourier transform and in certain limiting cases (like very high frequency,or very weak scatterer) it reduces to it.

The plan is to discuss some carefully crafted exmaples that show that Heisenberg's injunction about simultaneous concentration in the physical and the frequency domain do not hold (universally) for this transform: for instance, one can design highly "concentrated" radial potentials whose backscattering amplitude is a concentrated function of the wave number k.

This is very much an open area. I plan to introduce the problem, show some pictures for the one and three dimensional problem, and suggest an experiment that hopefully someone will be willing to carry out.

The original motivation for this "unnatural question" comes from medical imaging using Magnetic Resonance. In that case the scattering problem is a one dimensional Zakharov-Shabat two component system, and one wants to design "ultrashort" radio frequency pulses that would give very high spatial resolution.

The construction of fairly concentrated objects whose scattering amplitude has some concentration properties has potential importance in several areas of imaging.

3:30 pm	**Vincent Hall 502** (The IMA Lounge)	IMA Tea (and more!)

Tuesday, June 26

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:15 am	**Coffee break**	Reception Room EE/CS 3-176
9:30 am	**Louis Auslander** CUNY	Wavelets and Gabor bases, and their role in radar and sonar
10:00 am	**Brett Borden** NWC, China Lake, CA	Phase monopulse tracking and its relation to noncooperative target recognition

Abstract: We review the method of phase monopulse tracking and its associated "glint" problem. This problem was first examined more than 30 years ago but has yet to be successfully resolved. Nor shall WE attempt to solve it. Rather, we demonstrate how the very same data used for tracking can be used for target classification and recognition.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Daniel Goodfellow** Honeywell, Everett, WA	Detection probabilities for partially correlated signal fluctuations

Abstract: This presentation develops a model for representing partially correlated signal fluctuations. Swerling's pioneering paper [1] observed the need for modelling this situation and noted that his "fully-correlated" and "uncorrelated" models merely bound this more realistic case. To date, however, virtually all significant papers in this area, with the exception of reference [4], have limited themselves to Swerling's original correlation models (zero or one). Furthermore, most of these papers have dealt only with signal fluctuation distributions which are members of the chi-square family which we have found too restrictive to fit recent empirical sonar measurement data.

The proposed model allows the calculation of partially correlated signal fluctuation statistics for a broad class of fluctuation distributions. This class includes all finite-variance SNR distributions with a probability density function which can be represented as the convolution of two densities or for which a monotonic invertible function of the SNR can be represented as the convolution of two densities. It contains all of the classical fluctuating and non-fluctuating signal results listed in references [1-3] as special cases. In particular, it provides a a convenient form for modelling partially-correlated Log-Normal signal fluctuations which was the primary motivation for this work. The principal discussion topic of interest centers around efficient numerical computation of the model equations.

References:

1) Marcum, J.I., and P. Swerling, "Studies of Target Detection of Pulsed Radar", IRE Transactions on Information Theory, Vol IT-6, April 1960.

2) Heidbreder, G.R., and R.L. Mitchell, "Detection Probabilities for Log-normally Distributed Signals", IEEE Transactions, Vol AES-3, No. 1, January 1967, pp 5-13.

3) Robertson, G.H., "Operating Characteristics for a Linear Detector of CW Signals in Narrow-Band Gaussian Noise", Bell System Technical Journal, April 1967, pp. 755-775.

4) Nutall, A.H., and E.S. Eby, "Signal-to-noise Ratio Requirements for Detection of Multiple Pulses Subject to Partially Correlated Fading with Chi-Squared Statistics of Various Degrees of Freedom", NUSC TR 7707, 2 June 1986.

11:30 am	**Howard Resnikoff** Aware Inc., Cambridge, MA	Relationships between Fourier analysis and compactly supported wavelet expansions
2:00 pm	**José M. F. Moura** Carnegie Mellon University	Performance evaluation in sonar multipath problems

Abstract: Positioning systems (active or passive) localize targets by maximizing in parameter space a generalized cross-ambiguity function. When the propagation medium is inhomogeneous, the received signal is actually a noisy superposition of filtered correlated versions of the transmitted signal (multipath). Traditionally, multipath is dealt with as a nuisance that degrades the receiver performance. However, by taking into account the propagation effects (so called matched field processing), one processes coherently the available replicas achieving performance enhancement. The talk explores what the (local) performance limits are when multipath is present and derives performance, bounds for localization that exhibit the tradeoff between temporal processing techniques (multiple paths) and spatial processing methods (multiple sensor arrays).

2:30 pm	**Mos Kaveh** University of Minnesota	Rethinking the formulation of signal-subspace direction-of-arrival estimators

Abstract: Certain functionals of two vectors are proposed as models for the formulation of signal-subspace estimators of the directions of arrival of signals by an array of sensors. The two vectors are the projections of the array steering vector onto i) the subspace spanned by the noise and the least significant signal eigenvector

and ii) the least significant signal eigenvector. It is shown that the now "classical" MUSIC and Minimum-Norm estimators are based on special cases of these functionals. It is further shown that the choice of the functional significantly affects estimator performance, with some providing resolution and mean-squared error thresholds similar to rooting techniques which are only applicable to linear uniform array models.

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Wednesday, June 27

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:15 am	**Coffee Break**	Reception Room EE/CS 3-176
9:30 am	**Izador Gertner** CUNY	The finite Zak transform
10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Harold Naparst** Fidelity Management Co., Boston	The connection between wavelets and dense target radar imaging

Abstract: The method of "wavelets" refers to a decomposition of a function $e(t)$ into shifted and translated versions of an "analyzing wavelet" $s(t)$. If we regard $s(t)$ as the radar signal and $e(t)$ as the echo from a dense target environment D, then I have previously given a way to choose a set of signals so as to be able to reconstruct D from the echoes corresponding to those signals.

Now it seems that the "wavelet theory" is moving closer to the same goal, although the dense target application has not been discussed as such in wavelet literature. So far, however, the structure of the solutions are quite different. This is somewhat surprising, since at bottom is the same idea: Fourier Analysis on the Affine Group.

We discuss this problem and hope to stimulate a solution.

2:00 pm	**Jorge P. Zubelli** UC Berkeley	Image reconstruction of the interior of bodies that diffuse radiation

Abstract: We shall describe a nonintrusive procedure to reconstruct certain internal characteristics of objects that diffuse as well as attenuate radiation. Our method is based on a model where diffusion and scattering of the radiation particles play an important role. The paths of such particles are therefore convoluted, in contradistinction with the linear paths of X-ray tomography. The reconstruction problem under consideration is much harder than the traditional one and requires a substantially larger computational power. On the other hand, it has potential applications to a number of areas where X-ray tomography would not be suitable. We shall present a few reconstructions that were obtained via computer simulations and point out some interesting problems arising from the above mentioned approach. Some of these results are reported in a recent paper in Science by Singer, Grunbaum, Kohn and Zubelli.

2:30 pm	**Gunter Meyer** Georgia Tech.	The parabolic Fock theory for a convex dielectric scatterer

Abstract: This talk deals with a high frequency asymptotic method for representing surface fields near the shadow boundary of a convex dielectric scatterer. It will be shown that the parabolic approximation of Fock to the scaler Helmholtz equation follows from elementary singular perturbation expansions. Together with similar consideration for the Leontovich (impedance) boundary conditions this approach provides a closed form solution of the approximating boundary value problem in terms of the Fock-van-der-Pol- Bremmer integral. The correct asymptotic limit of this integral will be established by standard residue and growth estimates.

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Thursday, June 28

Unless otherwise indicated, the talks today are in Conference Hall EE/CS 3-180

9:15 am **Coffee Break** Reception Room EE/CS 3-176

9:30 am **Jeffrey C. Allen** Fast matrix-vector multiplication for image restoration
Naval Ocean System Center, San Diego

Abstract: The regularized pseudoinverse of the m by n point-spread matrix A is

$$\hat{A} = (A^H A + \beta^2 I)^{-1} A^H.$$

It is assumed that $m \geq n$. The expansion of the displaced difference of this regularized pseudoinverse in an SVD is

$$\hat{A} - Z_m \hat{A} Z_n^H = \sum_{k=1}^{\alpha_+} d_k p_k q_k^H$$

where Z_m and Z_n correspond to m by m and n by n downshift operators. This permits the representation of the regularized pseudoinverse as a sum of products of lower triangular m by n Toeplitz matrices times n by n upper triangular Toeplitz matrices determined by the factors in the SVD:

$$\hat{A} = \sum_{k=1}^{\alpha_+} L(d_k p_k) U(q_k^H)$$

The multiplication of a vector by a Toeplitz matrix can be performed quickly as a convolution via any of several fast transforms:
(a) The FFT
(b) The Winograd Prime Factor DFT
(c) The Fast Hartley Transform
(d) Number theoretic Transforms (Mersenne, etc.)
The lower triangular Toeplitz matrix has the form

$$L(x) = \begin{bmatrix} x_1 & 0 & 0 & 0 & \cdots & 0 \\ x_2 & x_1 & 0 & 0 & \cdots & 0 \\ x_3 & x_2 & x_1 & 0 & \cdots & 0 \\ x_4 & x_3 & x_2 & x_1 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & 0 \\ x_n & x_{n-1} & x_{n-2} & x_{n-3} & \cdots & x_1 \\ \vdots & \vdots & \vdots & \vdots & \cdots & \vdots \\ x_m & x_{m-1} & x_{m-2} & x_{m-3} & \cdots & x_{m-n+1} \end{bmatrix}.$$

We have shown that when the point spread matrix A is Toeplitz, the displacement rank $\alpha_+(\hat{A})$ is four or less. This permits the rapid successive application of the regularized pseudoinverse to many different vectors for
(1) Restoration when the point spread function is separable.
(2) Restoration of tomographic projections when the point spread function has rotational invariance.
Joint work with J.M. Speiser and H.J. Whitehouse.

10:00 am **Luise Schuetz** Prediction of acousto elastic scattering and radiation
Naval Res. Lab., Washington, D.C.

Abstract: We consider the problem of predicting the scattering and radiation of acoustic fields by elastic structures in a parameter regime where the elastic behavior of the structure and the loading of the fluid must be considered as coupled effects. Such predictions have been made by a number of researchers using

collocation-based approaches; however, these solutions have been limited to very low frequencies. Since high frequency approximations are not valid down to this frequency range, there is considerable interest in extending the integral equation based appraoches to higher frequencies. We describe the obstacles to such a development as well as recent advances.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176

11:00 am	**Craig Poling** Honeywell (USD)	Sonar detection

Abstract: A detection problem arising in adaptive focused beam forming is presented. Partial progress toward the solution is discussed. Ideas and comments are solicited.

2:00 pm	**Richard Marino** Lincoln Laboratory, MIT	Laser radar imaging: Systems and techniques. I

Abstract: This talk describes both system and data processing issues associated with laser radar in general and the FIREPOND laser radar in particular. After highlighting the major components of the FIREPOND facility, detailed predictions of laser radar signatures are described. These predictions include the effects of target speckle, LO shot noise, and the net system point spread response. We then describe the results of applying tomographic techniques to both predicted and experimentally obtained range resolved, Doppler resolved, and range-Doppler resolved signatures. The relative merits of these imaging techniques, along with waveform design issues, are discussed.

2:30 pm	**Kenneth Schultz** Lincoln Laboratory, MIT	Laser radar imaging: Systems and techniques. II

Abstract: See the previous abstract.

3:0ᶜ ·m	**Round Table**	Vincent Hall 502

There will be two parts to this (approximately) one hour informal discussion:

1) A roud table on present problems in industry.

2) Planning for possible future radar-sonar meetings.

Light refreshments will be served.

6:30 pm	**Radar-Sonar Dinner** Grandma's Restaurant	Details about the dinner will be announced during the workshop

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Friday, June 29

Unless otherwise indicated, the talks today are in Conference Hall EE/CS 3-180

9:15 am	**Coffee Break**	Reception Room EE/CS 3-176

9:30 am	**Peter Maass** Technische Universität Berlin	Wideband approximation and wavelet transform

Abstract: Consider a signal ψ which is reflected by a (continuous or discrete) distribution of objects D. The echo e is given in the **wideband approximation** by

$$e(t) = \int\int D(x,y)\sqrt{y}\psi(y(t-x))dxdy \quad (1).$$

This equation can be expressed in terms of the **wavelet transform** L_ψ associated with the signal ψ, namely

$$e = cL_\psi^* D \quad (2).$$

Under certain restrictions on ψ the transform L_ψ^* is unitary and (2) is inverted - on $\overline{range(L_\psi)}$ - by L_ψ itself. Unfortunately the required properties for ψ are not met by any practical signal. In order to allow a large class of signals, e.g., $\psi \in \{\phi \mid \phi, \phi' \in L_2(\mathbf{R})\}$, the inversion formula has to be modified; $\tilde{D}$ denotes the projection of D onto $\overline{range(L_\psi)}$:

$$\tilde{D} = \frac{d}{dx} L_{d\psi e}.$$

Incorporating the echos from a set of signals allows the reconstruction in $\cup_{i=1}^{n} range(L_{\psi_i})$. Fast algorithms are known for the computation of the wavelet transform.

Moreover other Radar features, e.g., matched filter, correlation function, ambiguity, can conveniently be interpretated and investigated in wavelet terminology.

10:00 am **Gary Mohnkern** — Problems in stationarity for large acoustic arrays
Naval Ocean System Center, San Diego

Abstract: As acoustic receiving arrays become larger, several problems in the minimum variance distortionless response (MVDR) algorithm for frequency domain adaptive beamforming become apparent. As the physical dimensions of arrays become larger, the length of the discrete Fourier Transform (DFT) must become longer to assure coherence for the increased delays encountered between sensors. At the same time, the number of DFTs required to obtain a full rank matrix increases with the number of sensors. For a filled line array, this seems to imply that the amount of data which must be accumulated to obtain an acceptable estimate of the noise field for MVDR increases as the square of the length of the array. The problem is exacerbated because in realistic noise fields adding more sensors increases the range of eigenvalues, decreasing the numerical stability of the cross-spectral density matrix. Furthermore, a longer array has more spatial resolution, so that smaller motions of interferences and targets become significant nonstationarities. All of these make stationarity of the noise field a major problem in designing processing for large arrays. Several potential solutions will be discussed.

10:30 am **Coffee Break** — Reception Room EE/CS 3-176

11:00 am **Norman L. Owsley** — Sensor array signal processing: Wavenumber spectrum analysis or beamforming?
NUSC, New London, CT

Abstract: There is a significant amount of current research activity in the application of modern, high resolution power spectrum estimation techniques to the problem of estimating the wavenumber spectrum for a spatially distributed array of sensors. The theme of this ongoing research equates the ability to resolve discrete sources in wavenumber with the primary measure of performance. Invariantly, the highly regarded high resolution parametric wavenumber estimators are based on a prior knowledge of the total number of sources which are present, i.e. the detection problem has already been solved and the remaining problem is to resolve the soruces. Typically, an algorithm such as the Akaike information criterion (AIC) (see Wax 1985, for example) is referenced as the "detection" procedure for the determination of the number of sources. This ad hoc two step detect-then-resolve procedure has at least two fundamental problems, namely, the treatment of partially correlated noise and the detection of moving sources which may be at the detection threshold. This paper illustrates these issues and suggests that an approach using wideband adaptive beamforming-then-detect is more appropriate than wavenumber parametric spectrum estimation.

11:30 am **Charles L. Weigel** — A problem: Estimating phase
Honeywell (USD)

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CURRENT IMA PARTICIPANTS

POSTDOCTORAL MEMBERS FOR 1989-90 PROGRAM YEAR

NAME	PREVIOUS/PRESENT INSTITUTION
H. Scott Dumas	SUNY, Albany
Mohamed Elbialy	University of Cincinnati
Michael S. Jolly	Princeton University
Maciej Krupa	University of Houston
Stephane Laederich	Boston University
Debra Lewis	Cornell University
Kening Lu	Georgia Institute of Technology
Mary Silber	UC, Berkeley
Matthew W. Stafford	Loyola University
Mary Lou Zeeman	MIT

RADAR-SONAR VISITORS IN RESIDENCE

Jeffrey Allen	Naval Ocean Sys. C., San Diego	Jun 28 - Jun 29
Donald Aronson	University of Minnesota	
Louis Auslander	CUNY	Jun 24 - Jun 28
Marvin Bernfeld	Raytheon	Jun 18 - Jun 29
Richard E. Blahut	IBM	Jun 18 - Jun 22
Martin Blumlinger	Tech. U., Vienna	Jun 17 - Jun 29
Bret Borden	NWC, China Lake, CA	Jun 25 - Jun 26
Mikhail Brodsky	UC Berkeley	Jun 24 - Jun 29
Kevin Buckley	University of Minnesota	Jun 18 - Jun 29
Joseph Dcosta	University of Minnesota	
Efi Foufoula	University of Minnesota	
Avner Friedman	University of Minnesota	
Dave Garrett	UNISYS	Jun 18 - Jun 29
Izador Gertner	CUNY	Jun 24 - Jun 29
D.N. Ghosh Roy	Tech. Res. Assoc., Salt Lake City	Jun 17 - Jun 25
Daniel Goodfellow	Honeywell, Everett, WA	Jun 24 - Jun 29
Jared Gottlieb	Lockheed	Jun 17 - Jun 23
Leon Green	University of Minnesota	
Alberto Grunbaum	UC Berkeley	Jun 18 - Jun 29
Lijia Guo	University of Cincinnati	Jun 18 - Jun 25
Morton Hamermesh	University of Minnesota	Jun 25 - Jun 29
Evans Harrigan	Cray Research	Jun 25 - Jun 29
Doris Hinestroza	University of Cincinnati	Jun 18 - Jun 25
Keith Kastella	UNISYS	Jun 18 - Jun 29
Mostafa Kaveh	University of Minnesota	Jun 18 - Jun 29
Daniel M. Keenan	University of Virginia	Jun 18 - Jun 29
Fritz Keinert	Iowa State University	Jun 17 - Jun 22
Keith Kostella	UNISYS	Jun 18 - Jun 29
Praveen Kumar	University of Minnesota	
Douglas Lake	University of Virginia	Jun 18 - Jun 29
Bruce Lee	University of Minnesota	
M.F. Levy	Rutherford Appleton Labs., UK	Jun 17 - Jun 29
Brian Loe	Iowa State University	Jun 16 - Jun 23
Kening Lu	Georgia Institute of Technology	
Charles Lutes	UNYSYS	Jun 18 - Jun 29
Peter Maass	Technische Universität, Berlin	Jun 13 - Jun 29

Richard Marino	Lincoln Laboratory, MIT	Jun 18 - Jun 29
Gunter Meyer	Georgia Institute of Technology	Jun 25 - Jun 29
Willard Miller	University of Minnesota	
Ruth Miniowitz	McGill University	Jun 17 - Jun 29
Gary Mohnkern	Naval Ocean System C., San Diego	Jun 25 - Jun 30
Pierre Moulin	Washington University	Jun 23 - Jun 29
Jose Moura	Carnegie Mellon University	Jun 18 - Jun 29
David Munson	University of Illinois, Urbana	Jun 17 - Jun 21
Arje Nachman	AFOSR	Jun 25 - Jun 29
Harold Naparst	Fidelity Management Co., Boston	Jun 22 - Jun 29
Jerry Nelson	UNISYS	Jun 18 - Jun 29
Bob Numerich	Cray Research	Jun 18 - Jun 23
Joseph O'Sullivan	Washington University	Jun 18 - Jun 29
Julia Olkin	SRI International	Jun 17 - Jun 24
Norman Owsley	NUSC, New London, CT	Jun 28 - Jun 29
Rainer Picard	U. of Wisconsin, Milwaukee	Jun 17 - Jun 27
Craig Poling	Honeywell (USD)	Jun 18 - Jun 29
Howard Resnikoff	Aware Inc., Cambridge, MA	Jun 25 - Jun 29
Jung Sik Rno	University of Cincinnati	Jun 18 - Jun 29
D.N. Ghosh Roy		Jun 17 - Jun 25
Walter Schempp	Universitat Siegeu, West Germany	Jun 18 - Jun 29
Luise Schuetz	Naval Res. Lab., Washington, D.C.	Jun 18 - Jun 29
Kenneth Schultz	Lincoln Laboratory, MIT	Jun 24 - Jun 28
Robert Shore	Hanscom Air Force Base	Jun 24 - Jun 30
Jon Sjogren	AFOSR	Jun 18 - Jun 22
Donald Snyder	Washington University	Jun 25 - Jun 27
Gerald Sobelman	University of Minnesota	Jun 18 - Jun 29
Ephraim Sparrow	University of Minnesota	
Mark Stenoien	Honeywell	Jun 18 - Jun 28
Ahmed Tewfik	University of Minnesota	Jun 18 - Jun 29
Charles Weigel	Honeywell (USD)	Jun 18 - Jun 29
Hans Weinberger	University of Minnesota	
Harper J. Whitehouse	Naval Ocean System C., San Diego	Jun 17 - Jun 22
Calvin Wilcox	University of Utah	Jun 17 - Jul 1
Jorge P. Zubelli	UC Berkeley	Jun 18 - Jun 29

APPENDIX B: PROGRAM FOR TIME SERIES.

NSTITUTE FOR MATHEMATICS AND ITS APPLICATIONS

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IMA NEWSLETTER #164

July 1 - July 29, 1990

IMA Summer Program

NEW DIRECTIONS IN TIME SERIES ANALYSIS

July 2 - July 27, 1990

Organizing committee: Emanuel Parzen (chairman), David Brillinger, Murray Rosenblatt, Murad Taqqu, John Geweke, and Peter E. Caines

The theory and methods of time series analysis lie at the intersection of the mathematical, statistical, computational, and system sciences, and provide an elegant interplay among these disciplines. They provide the means of applying advanced mathematical ideas and theorems to contribute towards the solutions of very practical problems. Time series analysis is truly an *interdisciplinary* field, because development of its theory and methods requires *interaction* between the diverse disciplines in which it is being applied. To harness its great potential there must develop a community of statistical and other scientists who are educated and motivated to have a background in theory and methods of time series analysis adequate to handle the problems of time series analysis in *all* the fields in which they occur.

Most of the summer program talks will be held in Conference Hall 3-180 on the entry floor of the new Electrical Engineering/Computer Science Building. This building is located on the corner of Washington Avenue and Union Street, a block from the IMA Main Office. The conference hall is on the Ethernet and has a projection system for display of computer output. We will also make use of the IMA Seminar room, Vincent Hall 570, for more informal discussions.

In addition to the previously scheduled lectures, there will be many opportunities during the program for informal, impromptu lectures, computer demonstrations, round tables, and so forth. Participants are encouraged to bring along material they might want to present.

PARTICIPATING INSTITUTIONS:Georgia Institute of Technology, Indiana University, Iowa State University, Michigan State University, Northern Illinois University, Northwestern University, Ohio State University, Pennsylvania State University, Purdue University, University of Chicago, University of Cincinnati, University of Houston, University of Illinois (Chicago), University of Illinois (Urbana), University of Iowa, University of Manitoba, University of Michigan, University of Minnesota, University of Notre Dame, University of Pittsburgh, Wayne State University
PARTICIPATING CORPORATIONS:Bellcore, Cray Research, Eastman Kodak, General Motors, Honeywell, IBM, Motorola, 3M, UNISYS

SCHEDULE FOR JULY 1 - JULY 29

Week 1, July 2–6, 1990

NON-LINEAR AND NON-GAUSSIAN MODELS AND PROCESSES

Organizers: David Brillinger and Murray Rosenblatt

Topics include higher-order moments and spectra, bilinear systems, nonlinear processes, applications to astronomy, geophysics, engineering, simulation.

Monday, July 2

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:00 am	**Registration and coffee**	Reception Room EE/CS 3-176
9:30 am	**Murray Rosenblatt** UC San Diego	NonGaussian models
10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**George Papanicolau** Courant Institute	Direct and inverse problems for waves in random media
2:00 pm	**David Brillinger** UC Berkeley	NMR spectroscopy: a comparative test case for spectrum and mle methods

Abstract: This work presents a comparative investigation of two spectral moment-based identification procedures with each other and with the method of maximum likelihood, for the case of a bilinear system having observed input and corresponding output. Inputs considered to the system are pulse, pulse-pair and stochastic. A principal concern of the analysis is the examination of coupled frequencies. Relative advantages and disadvantages of the three identification procedures are mentioned. Advantages of the maximum likelihood approach include the availability of expressions for standard errors and efficiency in an asymptotic sense. It seems that each procedure has a role to play. The work is illustrated by the analysis of some data from NMR spectroscopy collected with stochastic input.

4:00 pm	**Vincent Hall 502** (The IMA Lounge)	IMA Tea (and more!)

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Tuesday, July 3

The talks today are in Conference Hall EE/CS 3-180

9:15 am	**Coffee Break**	Reception Room EE/CS 3-176

Morning Chair: M. Hinich

9:30 am	**J. G. Stevens** Naval Postgraduate School	Nonlinear modelling of time series using multivariate adaptive splines (MARS)

Abstract: Joint work with P.A.W. Lewis.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Chrysostomos L. Nikias** Northeastern University	Cepstra of higher order spectra: some new problems and applications

Abstract: The purpose of this talk is to present the definitions, properties, computation and applications of cepstra of higher-order spectra (bicepstrum and tricepstrum). In particular, two different computation

procedures are described based on singular value decomposition and multidimensional FFT operations. We show that for linear non-Gaussian proesses or deterministic signals, the differences of bicepstrum coefficients contain all the information concerning the phase of the process, whereas their sums contain the magnitude information.

We present methods based on higher-order cepstra for the following problems: (i) signal phase reconstruction from the phase of the bispectrum, (ii) signal reconstruction from only the phase (or magnitude) of higher-order spectra, (iii) time delay estimation from higher-order cross-spectra, and (iv) adaptive blind equalization from fourth-order statistics.

Afternoon Chair: E. Waymire

2:00 pm	**Jeffrey D. Scargle** NASA-Ames Research Center	Predictive deconvolution of chaotic and random processes

Abstract: This talk will discuss extensions of the classical theory of linear least-squares predictive deconvolution needed to detect, model, and separate chaotic and random processes in time series data.

The nature of chaotic processes will be discussed, and a number of simple examples exhibited and analyzed. The Wold Decomposition for stationary processes applies to all chaotic systems posessing an invariant measure, and shows that time series data produced by any such system can be written in the standard MOVING AVERAGE form $X = R*C$ ($R =$ white chaos and C a constant, not necessarily causal, but invertible filter). This is a very useful model for physical processes.

A deconvolution technique, which allows estimation of R and C from time series data X, will be demonstrated on synthetic data. Some toy processes – such as those connected with the Bernoulli shift, Lozi map, and the Smale horseshoe – have exact deconvolutions, and numerical results will be shown for others – including the Henon, logistic, and continued fraction maps.

An exact deconvolution of the general toral automorphism yields a surprsisingly simple representation for these processes. This and other results suggest that R is connected with symbolic dynamics. I will suggest a number of unsolved problems in this area.

Wednesday, July 4

4TH OF JULY PICNIC

10:00 am	Picnic at University of Minnesota Landscape Arboretum

A picnic will be set-up at the U of M Arboretum (near Chanhassen, Minnesota). A bus will start loading at the EE/CS building on Union Street at 9:30 am and will leave at 10:00 am. Box lunches will be provided. The bus will leave the Arboretum at about 3:30 pm to return to the EE/CS Building.

Thursday, July 5

Unless otherwise indicated, the talks today are in Conference Hall EE/CS 3-180

9:15 am	**Coffee Break**	Reception Room EE/CS 3-176

Session Chair: P. A. W. Lewis

9:30 am	**Jerry M. Mendel** University of Southern California	Harmonic retrieval using higher-order spectra

Abstract: An important problem in signal processing is that of estimating the frequencies and amplitudes of harmonics which are observed in additive colored Gaussian noise. In practice, the observed signals are contaminated with spatially and temporally colored noise of unknown power spectral density. We use a cumulant-based approach to solve this problem. To begin, we define the cumulants of complex processes. We then show that third-order cumulants of harmonic processes are zero; hence, we must use fourth-order cumulants. Our major theoretical result is: specific $1.D$ slices of the fourth-order cumulant of the noise

measurement for the direction of arrival and retrieval of harmonics in noise problems are identical with the autocorrelation of a related noiseless signal; hence, correlation based high resolution methods (e.g., MUSIC and min norm) may also be used with fourth-order cumulants. Simulation examples will be shown that demonstrate the effectiveness of our method.
Joint work with Ananthram Swami.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176

Session Chair: G. Papanicolau

11:00 am	**Akiva Yaglom** Acad. Sciences, USSR	Random fields and their applications to atmospheric physics
11:30 am	**M. Hinich** University of Texas	Non-minimum phase deconvolution of speech
11:50 am		Open Discussion

Abstract: Among other matters the discussion will concern questions about George Papanicolau's presentation earlier this week.

Afternoon Chair: J. D. Scargle

2:00 pm	**J. Sidorowich** UC Santa Cruz	Chaotic time series analysis: applications in prediction and noise reduction

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Friday, July 6

Unless otherwise indicated, the talks today are in Conference Hall EE/CS 3-180

9:15 am	**Coffee Break**	Reception Room EE/CS 3-176

Session Chair: M. E. Bock

9:30 am	**Tohru Ozaki** Inst. of Stat. Math., Tokyo	Identification of nonlinearities and non-Gaussianities in time series

Abstract: Many non-Gaussian time series can be regarded as an output of a deterministic nonlinear dynamical system driven by Gaussian white noise. They could also be regarded as an output of a deterministic nonlinear dynamical system. In real time series data analysis, it is not known whether the system noise is zero or not. Also the coefficients of the dynamical system are usually not accurately known. In this talk we give a maximum likelihood estimation method for these unknown parameters using a nonlinear Kalman filtering method. Application of the present method to some real non-Gaussian time series is shown with numerical results.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176

Session Chair: E. Parzen

11:00 am	**Howell Tong** University of Kent	Comments on some contrasting aspects of nonlinear time series

Afternoon Chair: K.-S. Lii

2:00 pm	**G. Giannakis** University of Virginia	A maximum likelihood viewpoint of cumulants and polyspectral measures for nonGaussian estimation and classification
2:20 pm	**P. Rothman** NYU	Characterization of the time irreversibility of stationary time series

2:40 pm **Martin Casdagli** State space reconstruction
Los Alamos Nat. Labs.

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Week 2, July 9–13, 1990

SELF-SIMILAR PROCESSES AND LONG-RANGE DEPENDENCE

Organizer: Murad Taqqu

Topics include time series with long memory self-similar processes, fractals, 1/f noise, stable noise. **Most of the talks for this week will be arranged after the participants arrive at the IMA.**

Monday, July 9

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:00 am **Registration and coffee** Reception Room EE/CS 3-176

Morning Chair: B. Mandelbrot

9:30 am **Mourad Taqqu** Self-similar processes and long-range dependence in time series: An overview
Boston University

Abstract: We shall give an overview on self-similar processes and long-range dependence. The goal is to introduce and tie together the areas of research that will be discussed in detail during this workshop. We will consider Gaussian and non-Gaussian models, including models related to stable noise that display high variability.

10:30 am **Coffee Break** Reception Room EE/CS 3-176

11-11:30 am **Michael T. Lacey** Self-similar processes as limits in dynamical systems
Indiana University

Abstract: Let (X, μ, T) be an (invertible) dynamical system, and for a function $f \in L^1(\mu)$ set $S_n f = f + \ldots + f_0 T^{m-1}$. We show that for a wide variety of H-self-similar, stationary increment processes $Y(t)$ there is an $f \in L^1(\mu)$ so that $m^{-H} S_{[mt]} f \overset{d}{\Rightarrow} Y(t)$. This holds in particular when $Y(t) = B_H(t)$, a fractional Brownian motion of index H. Moreover, for the especially interesting case of irrational rotations, we study the kind of functions f which generate $B_H(t)$ as a limit.

Afternoon Chair: M. Taqqu

2:00 pm **B. Mandelbrot** Multifractals
IBM/Yale

3-3:30 pm **Ed Waymire** Network scaling in structure function computations
Oregon State University

Abstract: Mathematical problems involving the asymptotic analysis of rooted random tree graphs and branching patterns for large numbers of vertices will be discussed from the point of view of predictions of edge distributions as a function of distance from the root. Predictions are compared to a river network data base and the role of self-similarity and scaling properties is described.

3:30 pm **Vincent Hall 502** IMA Tea (and more!)
(The IMA Lounge)

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Tuesday, July 10

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:15 am **Coffee Break** Reception Room EE/CS 3-176

Morning Chair: E. Parzen

9:30 am	**Wim Vervaat** Catholic University, Nijmegen	Ergodic properties of self-affine processes

Abstract: We call H-self-similar processes with stationary increments *self-affine*. They are invariant in distribution under the transformations $f \mapsto a^{-H} f(a\cdot)$ for $a > 0$ and $f \mapsto f(b + \cdot) - f(b)$. We review general properties such as existence of moments, continuity and differentiability of the sample paths and various types of bounded variation, with emphasis on those that can be obtained by application of the Ergodic Theorem. It is crucial that, for the latter, the first moment must exist but need not be finite.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11-11:30 am	**G. O'Brien** York University, Ontario	Self-similar processes and point processes

Abstract: We discuss the existence and properties of H-self similar processes with stationary increments of the form

$$X(t) = \int_{s=0}^{t} \int_{-\infty}^{\infty} |x|^H (\text{sign} x) \Pi(dx ds)$$

where Π is a point process in $[0, \infty) \times R$.

11:30-Noon	**Michael Keane** Delft U. of Technology	One-dependent processes

Afternoon Chair: Péter Major

2:00 am	**T. C. Sun** Wayne State University	Limit theorems for non-linear functions of a stationary Gaussian process
2:30-3 pm	**Norma Terrin** Carnegie Mellon University	Convergence of quadratic forms with long-range dependence
3:00-3:15 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:15-3:45 pm	**Florin Avram** Northeastern University	Convergence to the normal distribution by graph methods

Abstract: When establishing convergence to the nromal distribution by the method of moments, one is often lead to the study of a certain type of sums associated with graphs (when the graph is a cycle, this "graph-sum" is a product of Toeplitz matrices, and the asymptotics in this case was obtained by Szego (1958)).

Two results concerning the asymptotics of these general "graph-sums" have been obtained: An inequality which establishes their order of magnitude, as well as an exact limit theorem. The results show dependence on the bond matroid structure of the graph.

The main tool in establishing these results was showing that a Holder type inequality for multiple integrals of functions applied to linearly dependent arguments holds, provided certain rank conditions, known to physicists as the "power counting" conditions, are satisfied.

These methods are applied for establishing various central limit theorems for certain dependent sequences of random variables.

Wednesday, July 11

The talks today are in Conference Hall EE/CS 3-180

Morning Chair: M. Keane

9:00 am	**Péter Major** Hungarian Academy of Sciences	The large-scale limit of Dyson's vector-valued hierarchical model: The role of continuous symmetries

Abstract: In this talk we investigate the large-scale limit of Dyson's vector-valued model. From a probabilistic point of view the problem we are interested in is a problem for the limit distribution of partial sums of (dependent) random variables with an appropriate normalization. The main step of the proof consists of the investigation of the effect of the powers of an integral operator with respect to a starting function. Formally, this operator is very similar to the convolution of a function with itself. The main difference between these operators is that our integral operator contains a kernel, and because of this kernel the stability property of its fixed points is more complex. Just because of this more sophisticated stability property a much richer picture of limit theorem behaviour arises. In particular, in the case of vector-valued models the continuous symmetry of the model has far-reaching and unexpected consequences. The subject of the present talk is the discussion of these consequences. The talk is based on our papers listed below and some investigations under progress.

References:

[1] Bleher, P. M., Major, P.: Critical phenomena and universal exponents in statistical physics. On Dyson's hierarchical model. *Annals of Probability* 15 1987, 431–477. (Special invited paper)

[2] Bleher, P. M., Major, P.: The large-scale limit of Dyson's hierarchical vector-valued model at low temperatures. The non-Gaussian case. Part I. *Annales de l'Institut Henri Poincaré*, Série Physique Théorique, Volume 49 fascicule 1 (1988), 1–85

[3] Bleher, P. M., Major, P.: The large-scale limit of Dyson's hierarchic al model at low temperatures. The non-Gaussian case. Part II. *Annales de l'Institut Henri Poincaré*, Série Physique Théorique, Volume 49 fascicule 1 (1988), 86–143

[4] Bleher, P. M., Major, P.: The large-scale limit of Dyson's hierarchic al vector-valued model at low temperatures. The marginal case $c = \sqrt{2}$. *Comm. Math. Physics* 125 (1989), 43–69

Joint work with P. M. Bleher.

10:00 am	**Coffee Break**	Reception Room EE/CS 3-176
10:30-11 am	**P. M. Bleher** Keldysh Inst. App. Math, Moscow	Statistical properties of a particle moving among a periodic set of scatterers
11:00 am	**Coffee Break**	Reception Room EE/CS 3-176
11:15-11:45 am	**Jim Kuelbs** University of Wisconsin	Rates of clustering for some Gaussian self-similar processes

Abstract: The analogue of Strassen's function LIL is known for many Gaussian processes which have suitable scaling properties, and here we establish rates at which this convergence takes place. In particular, our methods apply to Brownian motion, the Brownian sheet, and fractional Brownian motions.

Afternoon Chair: H. Dehling

2:00 pm	**Victor Solo** The Johns Hopkins University	Intrinsic random functions and the paradox of $1/f$ noise

Abstract: A Flicker Noise or $1/f$ noise is a Stochastic Process with low frequency spectrum of the form $\omega^{-\alpha}$. Such processes seem to be ubiquitous having been observed in such areas as; traffic flow, solid state devices, physiology, economics.

The paradox arises from the fact that for $\alpha \geq 1$ the spectrum is not integrable. This suggests that $1/f$ noise has infinite variance - thus it cannot be second order stationary and so cannot have a spectrum! Yet $\alpha \geq 1$ has been observed in practice along with evidence of certain "stationary-like" behaviour.

The problem has also appeared in another guise with Random Fields. Namely the polynomial variation of the variance of area and volume averages with area and volume, with exponents that cannot be attained by stationary models.

The idea (due to Mandlebrot and Matheron) that stationary increment processes (such as fractional Brownian motion, or the isotropic fractional Brownian Field) can explain these behaviours is pursued. In particular, the statistical behaviour of the Fourier Transform of a Stationary Increment process (or field) is shown to have the same statistical properties that it does in the stationary case (but not at zero frequency). Some new generalized Fejer theorems and central limit theorems are developed for this purpose.

The modelling of these processes will also be discussed. It turns out that the traditional log – log plot has a potentially enormous bias associated with it. Ways to get around this (including exact maximum likelihood estimation) are discussed. It is hoped to illustrate results with a data analysis of 1.4 million observations of resistance fluctuations of thin chromium film.

3:00 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:15-3:45 pm	**Adrian Papamarcou** University of Maryland	Stationary interval-valued probability models and long-range dependence

Abstract: Interval-valued probability is a generalization of numerical probability in which the likelihood of events is represented by two set functions, the *upper* and *lower probability*. These two functions are subadditive and superadditive, respectively, and reduce to finitely additive probability measures whenever they are identically equal.

In this talk we discuss potential applications of the interval-valued probability concept to the modeling of long-memory time series such as flicker noise encountered in high-quality quartz crystal oscillators. Although these processes occur in stable, "physically stationary," systems, they are not stationary in the conventional probabilistic sense of the term, as their empirical spectra are non-integrable. The possibility of finding stationary models for such processes in the broader realm of interval-valued probability remains open. A promising development towards this end is the construction of interval-valued probability models which combine features of strict stationarity and monotone continuity, yet violate the ergodic theorem by supporting almost sure divergence (instead of convergence) of time averages.

Thursday, July 12

Unless otherwise indicated, the talks today are in Conference Hall EE/CS 3-180

Morning Chair: Jeff Scargle

9:30 am	**Yoshihiro Yajima** University of Tokyo	Asymptotic properties of estimators for long memory time series

Abstract: Here we shall consider two problems. First we discuss a regression model with long memory stationary errors and derive a necessary and sufficient condition so that the least squares estimator be asymptotically efficient relative to the best linear unbiased estimator. Secondly we consider properties of an estimator when we fit a misspecified model such as ARMA model to long memory time series.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Jan Beran** Texas A&M University	Long-range dependence and linear regression, with special reference to ANOVA

Afternoon Chair: Z. Jurek

2-2:30 pm	**A. Yaglom** Acad. Sciences, USSR	Long-range dependence modeling of some geophysical and economics time series
2:30-3 pm	**Don Johnson** Rice University	Analysis of fractal intensity point processes

Abstract: Will show **REAL** data.

3:00 pm	**Coffee Break**	Reception Room EE/CS 3-176

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Joint Geometry Supercomputer Project & IMA Presentation

3:30 pm	**Benoît B. Mandelbrot** IBM/Yale	Fractals: Science and Music

Abstract: Dr. Mandelbrot will present a video of "New York Notes", a show of fractals and accompanying music by Charles Wuorinen which premiered at the Guggenheim Museum in April, 1990. The show will be followed by a short talk.

The PRESENTATION will take place in Lecture Hall EE/CS 3-210

Friday, July 13

Unless otherwise indicated, the talks today are in Conference Hall EE/CS 3-180

Morning Chair: J. Peyriere

9:30 am	**Yuri A. Davydov** Leningrad State University	On the distributions of multiple Wiener-Ito integrals
10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11:00 am	**Gennady Samorodnitsky** Cornell University	Integrability of the sample paths of stable processes

Afternoon Chair: Ed Waymire

2-2:30 pm	**Herold Dehling** Groningen	Estimating the marginal distribution in a long range dependent time series
2:30-3 pm	**Jacques Peyriere** Universite de Paris Sud, Orsay	On multifractals analysis of processes
3:00 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:15-3:45 pm	**Michael Keane** Delft U. of Technology	Self-affine processes of zero entropy

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Week 3, July 16–20, 1990

INTERACTIONS OF TIME SERIES AND STATISTICS

Organizer: Emanuel Parzen

Topics include time series model identification, analysis of categorical valued time series, nonparametric and semiparametric methods for time series.

Monday, July 16

Unless othe wise stated, the talks today are in Conference Hall EE/CS 3-180
The talks today are dedicated in honor of
John Tukey's contributions in Time Series Analysis.

9:00 am	**Registration and coffee**	Reception Room EE/CS 3-176

Morning Chair: Wayne Fuller

9:30 am **Emanuel Parzen** Time series, statistics, and information
Texas A&M University

Abstract: This paper is a broad survey of ideas for the future development of statistical methods of time series analysis based on investigating the many levels of relationships between time series analysis, statistical methods unification, and inverse problems with positivity constraints. It is hoped that developing these relations will: provide research tools for applied and theoretical statisticians in the 1990's and coming era of statistical information; make possible unification of statistical methods and the development of statistical culture. Topics discussed include:

1. Traditional entropy and cross-entropy,
2. Renyi and Chi-square information divergence,
3. Comparison density functions,
4. Approximation of positive functions (density functions) by minimum information divergence (maximum entropy),
5. Equivalence and orthogonality of normal time series,
6. Asymptotic information of stationary normal time series,
7. Estimation of finite parameter spectral densities,
8. Minimum information estimation of spectral densities and power index correlations,
9. Tail classification of probability laws and spectral densities,
10. Sample Brownian Bridge exploratory analysis of time series.

10:30 am **Coffee Break** Reception Room EE/CS 3-176

11:00 am **Peter M. Robinson** Semiparametric methods in time series
London School of Economics

Abstract: A variety of methods of semiparametric inference in time series are discussed, each involving some form of smoothed estimation of a nonparametric component. Four main topics are covered. The first is efficient or robust inference on regression-type models in the presence of disturbance autocorrelation of unknown form, with extension to multiple systems in which only some equations are parameterised and the full system has a nonparametric frequency response function. Nonparametric spectral and cross-spectral estimation is involved here, and some discussion of automatic bandwidth determination is included. In the second topic the spectral density itself has a semiparametric character. In a time series exhibiting long-memory behaviour, the logged spectrum is dominated near the origin by a linear component, with unknown slope, but nonparametric effects can be significant at other frequencies, as when no attempt is made to parameterise the smooth spectrum of a fractionally differenced process. Several methods of estimation, and their impact on the first topic, are discussed. The third topic concerns semiparametric models for time series in which even getting root-n-consistent parameter estimates is challenging, and smoothed nonparametric regression and derivative-of-probability-density estimation plays a useful role. Such models include ones for discrete-valued and censored time series, whose conditional expectation given explanatory variables is a nonparametric function of a linear combination, and regression models containing both a parametric and a nonparametric component. It is possible to estimate parameters up to unknown scale, and carry out tests of certain hypotheses. The final topic is concerned with developing tests with good consistency properties, based on an approximation of the Kullback-Leibler information criterion which employs nonparametric probability density estimates. The main application is to testing for independence in time series with marginal density of unknown form; another is to testing for reversability in time series.

Afternoon Chair: Emanuel Parzen

2:00 pm **Scott Zeger** Regression models for discrete time series
John Hopkins University

Abstract: Linear regression models for Gaussian time series data $\{y_t, t = 1, \ldots, n\}$ are in common use. A linear model has two parts: a regression in which $E(y_t)$ is expressed as a function of a covariate vector x_t; and a parametric, typically ARMA, model for the correlation in the residual series $\{\varepsilon_t, t = 1, \ldots, n\}$. A desireable property of linear models is that the interpretation of regression coefficients is invariant with

respect to the choice of the correlation model. In fact it quite generally possible to make consistent inferences for regression coefficients when the correlation model is incorrectly specified given a stationary error series.

Regression models for binary or count time series are less commonly used and do not necessarily share the model robustness mentioned above. In most cases, the interpretation of regression coefficients is tightly bound up with the model for time dependence. This is because time series extensions of the common regression models for independent discrete data are neither linear, additive nor stationary. One exception is the class of "marginal" models in which a known function of the marginal expectation of y_t is assumed to depend linearly on x_t, i.e. $h(Ey_t) = x_t\beta$. For example, with binary responses, the logit (log odds) of the marginal probability of a success is modelled; with count data, the log of the expected count is expressed in terms of x_t.

This talk will discuss marginal models for discrete time series data. Time dependence is accounted for by modelling the covariance matrix of the sequence $\{y_t, t = 1, \ldots, n\}$ as a function of the marginal mean and of additional covariance parameters α. Estimation is performed using "generalized estimating equations" (GEE). The methods will be illustrated with time series data from public health research.

3:00 pm	**John W. Tukey** Princeton University	Reflections
4:15 pm	**Vincent Hall 502** (The IMA Lounge)	Reception in honor of John Tukey

Tuesday, July 17

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

Morning Chair: Ludwig Fahmier

8:30 am	**Ludwig Fahrmeir** University of Regensburg, F.R.G.	State space modeling and conditional mode estimation for categorical time series

Abstract: In this talk the following state space models for time series of ordered or unordered categorical responses are considered: Conditional upon time-varying parameters or states, observation models are dynamic versions of categorical response models for cross-sectional data. State transition models may be Gaussian or not.

As an alternative to conditional mean filtering and smoothing, which generally will require repeated multidimensional integrations, estimation is based on modes of the posterior distribution. Factorization of the conditional information matrix leads to Gauss-Newton iterations which are closely related to extended Kalman filtering for non-Gaussian data. Estimation of unknown hyperstructural parameters is discussed and the methods are illustrated by some examples. Relations to non- and semiparametric approaches are outlined.

Finally, extensions to general non-Gaussian state space models are indicated.

9:30 am	**Coffee Break**	Reception Room EE/CS 3-176
10-10:30 am	**Ed Carlstein** University of North Carolina	Resampling for time series

Abstract: Resampling enables us to nonparametrically estimate features of the distribution of a general statistic T, using only the n observations at hand. Particular features which may interest us include the mean, variance, skewness, and percentiles of T's distribution. The fundamental strategy in resampling is to generate "replicates" of T from the available data, and then use these replicates to model the true sampling distribution of T. The jackknife, the bootstrap, and the typical-value principle are specific resampling algorithms for generating replicates; these methods were first introduced and extensively studied in the case where the original observations are iid. When the observations are serially dependent (but stationary), the resampling algorithms must be modified in order to yield valid replicates of T. The modified resampling algorithms can be model-based (i.e., they can exploit an assumed dependence structure in the time series) or

model-free (i.e., no knowledge of the dependence mechanism is needed). Model-based resampling algorithms include the Markovian bootstrap and bootstrapping of residuals; model-free approaches include the blockwise jackknife, the blockwise bootstrap, the linked blockwise bootstrap, and subseries methods.

10:30-11 am	**Clifford M. Hurvich** New York University,	Selection of time series models and spectrum estimates using a bias-corrected generalization of AIC

Abstract: We address a general selection problem for time series, namely: Given data from a stationary Gaussian process having a spectral density, and given a class C of candidate spectrum estimates, how should one select a candidate from C for use as a description of the process? Special cases of this problem include order selection for autoregressive models and spectrum estimates, as well as bandwidth selection for nonparametric spectrum estimates. In this paper, we discuss AIC_C, (a bias-corrected generalization of the well-known Akaike Information criterion AIC) which provides a unified solution to the problem. For autoregressive order selection, AIC_C is asymptotically equivalent to AIC, is asymptotically efficient, and provides superior selections in small samples, as shown in Hurvich and Tsai (1989). For nonparametric spectrum estimation, AIC_C produces good bandwidth selections, as shown in Hurvich and Beltrao (1990). Further, if one allows the class C of candidates to simultaneously contain parametric and nonparametric spectrum estimates, then AIC_C allows the data-driven selection of estimate type (e.g., autoregressive or nonparametric) as well as the corresponding smoothness parameter (e.g., model order or bandwidth). Finally, we briefly discuss some recent improvements in AIC_C for selection of autoregressive models, based on numerical tabulation of penalty functions.

11:15-Noon		Informal Discussions, Expanded Presentations

Afternoon Chair: Ludwig Fahmier

1:30 pm	**Mohsen Pourahmadi** Northern Illinois University	Can the idea of regression provide a foundation for time series analysis?

Abstract: Time series analysis as an area of statistics does not seem to have an easily accessible foundation emanating from probability theory or familiar statistical models. While regression methods are frequently used to analyze various time series data sets, other than the work of Wold the idea of regression in the finite dimension has not been used in the study of structure of stationary processes which is so crucial in the statistical analysis of time series. In this talk, by using an abstraction of the idea of linear regression, we extend the approach of Wold and obtain, essentially, all fundamental results concerning the structure of a stationary process in the time domain. In particular, we derive AR-, MA-, and ARMA- representations for a time series, and study the three crucial problems of prediction, interpolation, and computation of canonical correlations. This approach allows a new way of introducing and interpreting various parameters of a time series with useful pedagogical implications. Also, we compare this approach with the standard Kolmogorov-Wiener prediction theory which is developed in the spectral domain and can be viewed as regression in the the infinite dimension.

2:30 pm	**Coffee Break**	Reception Room EE/CS 3-176
3-3:30 pm	**R.J. Bhansali** University of Liverpool	Estimation of the forecast mean squared error and an R^2 measure for stationary time series

Abstract: For forecasting the future values of a stationary process, $\{x_t\}(t = 0, \pm 1, \pm 2, \ldots)$, on the basis of its past, two key parameters are the variance, $V(h)(h \geq 1)$, of the h-step forecasting error and $Z(h) = \{R(0) - V(h)\}/R(0)$, the corresponding R^2 measure of the predictability of x_t from its past, where $R(0)$ denotes the variance of x_t. The estimation of $V(h)$ and $Z(h)$ from a realization of T consecutive observations of $\{x_t\}$ is considered, without requiring that the process follows a finite parameter model. Three different autoregressive estimates are examined and shown to be asymptotically equivalent in the sense that as $T \to \infty$ they have the same asymptotic normal distributions. The question of bias in estimating these parameters is also examined and bias correction proposed. Some of the applications of the results are described.

3:30-4 pm	**H. Salehi** Michigan State University	Infinite order ARMA systems

Abstract: The structure of solutions to infinite order ARMA equations of the form

$$\sum \phi(k)X(n-k) = \sum \theta(k)Z(n-k), \qquad (*)$$

where summations are taken over all integers and $Z\{(k)\}$ is a discrete parameter white noise, is studied. As in the finite order ARMA models the functions

$$\phi(t) = \sum \phi(k)\exp(ikt) \quad \text{and} \quad \theta(t) = \sum \theta(k)\exp(ikt),$$

$t \in [0, 2\pi]$, play important roles in this study. In particular it is proved that $(*)$ has a harmonizable solution if and only if it has a stationary solution; and the later holds if and only if the quotient ϕ/θ is square integrable. Furthermore under some additional analytic conditions which are automatically met for finite-order ARMA systems it is shown that any L^2-bounded solution to $(*)$ is harmonizable.

Joint work with A. Makagon.

Wednesday, July 18

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

Morning Chair: Scott Zeger

8:30-9 am	**R. Shumway & D. Stoffer** UC Davis & U. of Pittsburgh	Dynamic linear models with switching
9-9:30 am	**D. Stoffer & K. Wall** U. of Pittsburgh & Naval Postgraduate School	Bootstrapping state space models
9:30 am	**Coffee Break**	Reception Room EE/CS 3-176
10-10:30 am	**Brockwell, Davis, Salehi** Melbourne, Colorado State & Michigan State Universities	A state space approach to transfer function modeling
10:30-11 am	**Richard A. Davis** Colorado State University	On noncausal AR processes: reversibility, identifiability, and estimation
1:30 pm	**Emanuel Parzen** Texas A.& M. University	On time series, statistics and information (continued)
2:30 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:00-4 pm		Forum

Abstract: All participants who are not speakers this week introduce themselves; general discussion of role of time series analysis in statistics; time series courses, books.

4-4:30 pm	**Jim Ramsey** NYU	Some exploratory techniques for discovery of nonlinear dynamics

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Thursday, July 19

Unless otherwise indicated, the talks today are in Conference Hall EE/CS 3-180

Morning Chair: Myron Katzoff

8:30 am **Gregory Reinsel**
University of Wisconsin, Madison

Modeling with reduced rank structures for stationary and nonstationary multivariate autoregressive models

Abstract: The analysis of vector autoregressive models which incorporate different forms of reduced-rank structure in their coefficient matrices is examined. To address the problem of increased complexity in the analysis of multiple time series $Y_t = (Y_{1t}, \ldots, Y_{kt})'$ as the number k of series grows, various approaches have recently begun to be investigated concerning specification and modeling techniques that identify and incorporate simplifying structures into the model (e.g., Ahn and Reinsel, 1988, Tiao and Tsay, 1989). In addition, investigations concerning the structure of the joint nonstationarity among multiple series, especially for economic time series data, have developed leading to interests in co-integration of multiple time series (Engle and Granger, 1987, Stock and Watson, 1988, Johansen, 1988). The need to adequately represent both the nature of nonstationarity among the series and the structural dependencies among parameters in the vector time series model is important for proper model specification, increased understanding, efficient prediction, and to avoid the difficulties associated with multivariate "over-differencing" (that is, over-specification of the number of unit roots) in nonstationary vector time series models. A useful approach for vector time series modeling involves a combination of the two structural modeling components associated with the dependencies among model parameters and with the nature of nonstationarity among series.

We are concerned with the vector autoregressive (AR) model for Y_t given by

$$Y_t = \sum_{j=1}^{p} \Phi_{t-j} + \varepsilon_t, \qquad 1$$

where Φ_j are $k \times k$ matrices of coefficients, and the ε_t are a k-dimensional white noise process with zero mean and covariance matrix $\sum$. Ahn and Reinsel (1988) studied the nested reduced-rank AR model where the rank of the coefficient matrix Φ_i is assumed to equal r_i and the r_i are nonincreasing as the lag i increases, with $\Phi_i = A_i B_i$, and the nested reduced rank assumption that $range(A_i) \supset range(A_{i+1})$ is imposed. The model is considered in order to simplify and provide a more detailed description of the structure of the vector time series model and to reduce the number of parameters in the modeling. Appropriate procedures, based on partial canonical correlation analysis between Y_t and Y_{t-j}, to identify the reduced rank structure are described, procedures for Gaussian estimation of parameters in the specified reduced rank model are presented, and properties of the Gaussian estimators are provided.

Another situation of special interest occurs when Y_t is nonstationary with $\det\{\Phi(B)\} = 0$ having $d < k$ unit roots and all other roots are outside the unit circle. It is also assumed that $rank\{\Phi(1)\} = r, r = k - d$, which implies that each component of the first differences $W_t = Y_t - Y_{t-1}$ is stationary. The model can then be expressed in the error-correction form as

$$W_t = CY_{t-1} + \sum_{j=1}^{p-1} W_{t-j} + \varepsilon_t, \qquad 2$$

where $C = -\Phi(1) \equiv AB$ is of reduced rank $r = k - d$, and $\Phi_j^* = \sum_{i=j+1}^{p} \Phi_i$. One implication of such models is that although all k component series may exhibit nonstationary behavior, there are r linear combinations of Y_t which are stationary, and hence there is a reduced dimensionality to the nature of the nonstationarity among the k series. Recent work by Ahn and Reinsel (1990) and others on Gaussian estimation procedures for the model (2) with the reduced rank structure for C imposed (that is, with d unit roots imposed on the AR operator in (1)) and asymptotic properties of the estimators is reviewed. Also investigated are the asymptotic properties of the likelihood ratio statistic to test for the number of unit roots d in the model, that is, the rank r of the matrix C. In addition, it is noted that if a nonstationary (unit root) AR model (1) has a nested reduced-rank structure, then the coefficient matrices Φ_j^* in the error-correction form (2) will also possess a nested reduced-rank structure. Hence, such a model will combine the reduced-rank structure for the matrix C to represent the reduced dimensionality in the long-term (nonstationary) dynamics of the process

and a separate nested reduced-rank structure for the matrices Φ_j^* to represent the shorter-term (stationary) dynamics. Gaussian estimation procedures for such combined reduced rank models and associated likelihood ratio testing procedures are described and their asymptotic properties are indicated. Numerical examples are considered to illustrate the nested AR and the nonstationary unit root reduced rank model specification and estimation methods.

9:30 am	**Coffee Break**	Reception Room EE/CS 3-176
10-10:30 am	**Jonathan D. Cryer** University of Iowa	Some exact distribution theory for inference in time series models

Abstract: When dealing with time series models, most of the distribution theory for estimators, test statistics, forecasts, and forecast errors must be approximate and based on asymptotics. This paper reviews some recent work on the exact distribution theory for inferential statistics associated with ARIMA models. This recent work has the effect of simplifying and extending much earlier work which considers distributions based on simulation or asymptotics.

10:30-11 am — Forum: Time series open questions

Afternoon Chair: Gregory Reinsel

1:30 pm	**Benjamin Kedem** University of Maryland	Contraction mappings in mixed spectrum estimation

Abstract: Families and sequences of zero-crossing counts generated by parametric time invariant filters are called higher order crossings or HOC. Because of the close relationship between zero-crossing counts and first order autocorrelations, families of first order autocorrelations are also referred to as HOC. By means of HOC from repeated differencing and repeated summation, it is possible to obtain a complete solution of the the problem of hidden periodicities in the purely discrete spectrum case. However, when noise is present, a modification is needed. It is shown how to locate discrete frequencies in the presence of colored noise, using HOC sequences obtained by recursive filtering. By this method, the cosine of each discrete frequency is obtained as a fixed point of a certain contraction mapping. A special feature of this method is that the contraction rate can be enhanced considerably by the iterative reduction in the filter bandwidth.

2:30 pm	**Coffee Break**	Reception Room EE/CS 3-176
3-3:30 pm	**Robert V. Foutz** VPI & SU	Small-sample spectral estimation

Abstract: A general technique is described for estimating spectral parameters for multiple time series; including spectral densities, coherence, phase and group delay. The primary purpose of the technique is to provide point estimators that are uniformly minimum variance unbiased (UMVU), under certain ideal conditions, and also to provide confidence interval estimators that have exact confidence coefficients when the ideal conditions are met. Because the proposed techniques may have known properties for each fixed sample size, they may be of use in small samples where the exact properties of the standard asymptotic procedures are not known. An example concerns the time series Z_1 of the annual harvest of Maine lobsters and the time series Z_2 of annual sea surface temperatures at Boothbay Harbor, Maine. A small sample of eighty-eight annual Z_1, Z_2 values is used to compute the periodogram and cross periodogram ordinates at the Fourier frequencies, then appropriate functions of these are transformed to satisfy linear models with independent, normal errors. It is shown that a method due to Neyman and Scott leads to UMVU estimators for functions of the spectral densities of Z_1 and Z_2, the squared coherence between Z_1 and Z_2, and the phase spectrum between Z_1 and Z_2. In addition, exact 81% confidence intervals are obtained for these spectral parameters and also for the group delay between the Z_1 and Z_2 series.

Joint work with Philip J. Ramsey.

3:30-4 pm	**S. Mittnik** SUNY Stony Brook	State space modeling of non-linear time series and chaos

5:45 pm	**Time Series Dinner**	Buffet dinner at the Campus Club, Coffman Union, 4th floor. Wine and cheese served at 5:45 pm, dinner at 6:30 pm.

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Friday, July 20

Unless otherwise indicated, the talks today are in Conference Hall EE/CS 3-180

Morning Chair: Mohsen Pourahmadi

8:30 am	**Wayne Fuller** Iowa State University	Nonlinear estimation for time-series

Abstract: Estimation for nonlinear models in which some of the variables are time series is investigated. Large sample results for models in which the sum of squares of the derivatives increase at different rates are obtained. Example models include the linear model with autoregressive errors, the autoregressive moving average with an autoregressive unit root and models with time trends.

Joint work with Neerchal K. Nagaraj.

9:30 am	**Coffee Break**	Reception Room EE/CS 3-176
10-10:30 am	**Young K. Truong** University of North Carolina	A nonparametric framework for time series analysis

Abstract: Much of time series analysis deals with inference concerning the unknows in the stochastic model for a random phenomena. In parametric approach the unknowns are a specific finite number of parameters while in the nonparametric approach they are smooth functions. In this paper, the problem of estimating the conditional mean and conditional median functions involving time series is considered. Specifically, the effect of correlated structure on smoothing procedures such as kernel method based on local mean and local median will be examined, and recent results on selecting a sequence of estimators that achieves the optimal rates of convergence will also be addressed.

10:30-11 am	**Bill Dunsmuir** Bond University, Queensland	L1 estimation for stationary time series models

Abstract: This paper will review L1 estimation for stationary time series models. In particular the asymptotic properties of the parameter estimates will be reviewed and some finite sample simulation results presented. Use of linear programming methods for obtaining the estimates will be discussed and applied to some monthly product data.

Afternoon Chair: Peter Brockwell

1:30 pm	**Madan L. Puri** Indiana University	Rank-based methods in time series analysis
2:30 pm	**Coffee Break**	Reception Room EE/CS 3-176
3-3:30 pm	**Greta Ljung** MIT	Missing values and outliers in time series
3:30-4 pm	**Jovan Malisic** Belgrade U., Yugoslavia	Stationary AREX time series models

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Week 4, July 23–27, 1990

TIME SERIES RESEARCH COMMON TO ENGINEERS AND ECONOMISTS

Organizers: John Geweke and Peter Caines

Topics will include modeling of multivariate (possibly non-stationary) time series, especially by state space and adaptive methods.

Monday, July 23

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

10:00 am	**Registration and coffee**	Reception Room EE/CS 3-176

Afternoon Topic: Structural Problems in Econometrics & TSA

Afternoon Chair: Peter Caines

12:45-1 pm	**A. Friedman & W. Miller** IMA	Welcome and orientation
1-1:30 pm	**Cornelis A. Los** University of Florida	A scientific view of economic data analysis (Kalman's theory for the identification of linear relations applied)

Abstract: Identification of systems from data is one of the basic problems of science and, automatically, a central problem of system theory. When the data is exact, the problem is well understood; in principle, since Newton ("hypotheses non fingo"). When the data is noisy, attempts have been made to deal with the problem for more than a century, but the results (Galton's "regression") are wrong or at least unsatisfactory. The reason is diagnosed to be a problem of prejudice. This means,
(i) in mathematics: asking the wrong questions (so-called "ill-posed problems", e.g. Tikhonov's numerical computation example);
(ii) in econometrics: assuming a model without reference to the data and without evidence that the data was generated by such a model (e.g., the Cobb-Douglas production function), and so misusing the word "identification";
(iii) in statistics: assuming that any data is the result of independent random sampling (the "standard statistical prejudice"), and then implementing the nonidentifying maximum likelihood method.
In all cases, the difficulty is that additional, ad-hod assumptions are imposed on the data, which in effect means assuming more data than there is. The results of such analyses usualy depend on the prejudices and not on the data.
Prejudice-free identification means that the data is allowed to speak for itself. How this can be done will be illustrated by the analysis of the "regression" problem. A new formulation of this problem will be presented (essentially the problem of defining the rank of a nonnegative definite matrix), from which new methods for prejudice-free identification have been deduced. This implies, for the first time since Gauss, the development of new theorems (Kalman) concerning least squares.
The emphasis in this paper will be on explaining what went wrong with "regression" analysis (and its derivatives) and on illustrating the new theorems with examples partly drawn from the academic (mathematical and economic literature and partly from empirical (Wallstreet) practice.

1:30-2 pm	**B. Hanzon** Free University of Amsterdam	On parameter-independent characterizations of the structure of a linear dynamical model

Abstract: Often the structure of a model is described by putting certain parameters equal to zero or one (or some other fixed value). For several reasons (to gain better understanding and to be able to apply overlapping parametrization methods etc.) it is desirable to have parameter-independent characterizations of such a structure.One approach is to study the Hankel matrix of a linear dynamical model. It is independent of the parametrization of the model. Its linear algebraic structure can reveal many of the well-known determinants of the structure, like the McMillan degree, the Kronecker indices, the Cauchy index and the degrees p, q of an ARMA(p, q) representation. Another approach takes a more geometrical point of view. It is argued that if one considers the class of all models with some given stucture (for instance the maximal delay in each of the equations of a multivariable ARMA model) then one has effectively also the boundaries in the model set (within any positive tolerance level). Therefore we will take these boundaries into account. E.g., for multivariable ARMA models we are led to the specialization order.

The number and choice of inputs and outputs are part of the structure of a model. Taking this into account as well, leads to a nice compact geometrical set-up for families of linear systems. Some examples will be given of how a family of systems with a certain structure looks like geometrically. The structure of the system is reflected in the geometrical structure of the family. There are direct links with questions of (overlapping) parametrizations, model order reduction and recursive and nonrecursive system identification.

2:00 pm	**A. Lindquist** Royal Inst. of Tech., Stockholm	Stochastic realization theory & factor analysis in TSA
3-3:30 pm	**Andrea Gombani** Corso Stati Uniti 4, Padova	Approximate stochastic realizations

Abstract: The problem we consider here occurs quite frequently in the construction of Markovian representations of a stochastic process y. There is a complete and general theory (see e.g., Lindquist, Picci [1]) to construct an exact stochastic realization of y, which makes use of the factorization of the spectral density $F(z)$. Nevertheless, if the degree of the density is very high, the realization we obtain is not very useful for computational purposes. This sometimes happens because, in presence of noise in the data, the estimation procedure for the density generates some unnecessary poles. The question we try to answer in this paper is whether these redundant poles can be eliminated through some reasonable approximation procedure. The idea is to start with an exact realization (no matter how large) of the process y, and then seek an approximate submodel (in the sense explained below) within the state space of this original model. The submodel which best represents y within all submodels of a fixed degree k is our approximant. This yields an interesting representation of a Markovian space through a Markovian basis, and sets up a correspondence of this basis with the Malmquist basis in the spectral domain ([2]). Then it is shown that a minimal realization can be obtained with a very simple algorithm of polynomial from a nonminimal one, and that this algorithm can be extended to give an approximate realization of fixed degree k (see [3]). We also show that different realizations yield different approximation errors, and discuss how to choose the representation which gives the best approximant.
[1] Lindquist A., Picci G., Realization Theory for *Multivariate* Stationary Gaussian Processes, SIAM J. Control and Optimization, Vol 23, No. 6, 1985, 809-857. [2] Nikol'skii, N.K., Treatise on the shift operator, Spinger- Verlag, 1986. [3] Gombani A., Consistent approximations of linear stochastic models, SIAM Journal on Control and Optimization, 27, 1989, 83-107.
Joint work with Claudia Polini.

4:00 pm	**Vincent Hall 502** (The IMA Lounge)	IMA Tea (and more!)

Tuesday, July 24

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:15 am	**Coffee Break**	Reception Room EE/CS 3-176

Morning Topic: Complexity in System Identification & TSA

Morning Chair: Manfred Deistler

9:30-10 am	**L. Gérencsér** McGill University	Stochastic complexity and modelling

Abstract: We present the highlights of the theory of stochastic complexity as developed in the last few years, with special attential to the problem of modelling linear stochastic systems. We discuss the effect of the uncertainty due to estimation of parameters onto prediction errors (Davisson's formula), and we also discuss the basic inequality of the theory (Rissanen, Ann. of Stat's). Several almost sure asymptotic results for a computable version of the so-called predictive stochastic complexity will be given, both for ARMA processes and for multivariable systems. Recent applications of the theory of stochastic complexity in cluster analysis and computer vision indicate that a particularly exciting trend of the theory is the analysis of nonparametric

problems. As an illustration we give asymptotic results of the approximation of linear stochastic systems by an $AR(\infty)$ system.

10-10:30 am	**C.Z. Wei** University of Maryland	On predictive least squares principles
10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11-11:30 am	**J. Baikovicius & L. Gérencsér** McGill University	Change point detection in a stochastic complexity framework

Abstract: We present a new method for solving the change point detection problem for ARMA systems which are assumed to have a slow and non-decaying drift after the change occurs. The proposed technique is inspired by the stochastic complexity theory, which gives a basis of comparison of different models with different change point times. Some partial results on the analysis of the estimator are stated. Several simulations are included which show that the approach exhibits surprisingly good detection capabilities. They also illustrate the robustness of the detectors with respect to a window size w and the rate of change of the slowly time-varying system.

11:30-Noon	**J.M. Maciejowski** Cambridge University	Balanced realizations, linear systems, and identification

Abstract: We have had a program of research into the use of balanced realizations for system identification for some time. This talk will review the motivation for this, the results already published, and give some account of current work.

The basic idea is to identify linear systems and time series in state-space form, and to use balanced realizations as canonical forms, rather than the more usual canonical forms based on selecting linearly independent rows from a Hankel matrix. Perceived possible advantages of doing this are (1) that it may be easier to handle changes in assumptions about the McMillan degree, (we do not wish to assume that this is known a priori), and (2) that better performance of estimation may result, essentially because of better numerical conditioning.

We have obtained a lot of new results in system theory, which are directly useful for system identification, but a lot is still left to do. For example, even points (1) and (2) above are by no means established.

The fundamental result is that balanced realizations are indeed true canonical forms for linear systems, and that we have explicit parametrizations for these realizations. Furthermore, similar balanced canonical forms and parametrizations can be obtained for several sub-classes of linear systems. The most important ones for identification are: asymptotically stable systems, minimum phase systems, and predictors. So we have a parametrization, for instance, which has the property that as the parameters range over a simple open subset of Euclidean space, generates predictors of given McMillan degree; there are no nasty hypersurfaces at which the McMillan degree may drop. The most important implication of this is that parameter estimation can be performed using unconstrained optimization. All the results of this type apply to multi-input, multi-output systems.

The set of linear systems of given McMillan degree and input-output dimensions is known to be a differentiable manifold. We are using our balanced parametrizations to investigate the Riemannian geometry of this manifold. Exploiting results obtained by Hanzon, we use computer algebra to compute Riemannian metrics, curvature tensors, etc. The purpose of this is both to try to obtain an understanding of the intrinsic geometry, and to develop parameter estimation algorithms which take account of that geometry - computing gradients which are 'intrinsic' to the manifold, for example. To date, everything has been done using an L_2 norm of systems. We hope to investigate other norms in the future.

It was established a long time ago, by Kalman and Hazewinkel, that the set of (multivariable) linear systems of a given McMillan degree cannot be parametrized by a single, continuous canonical form. The system identification problem therefore includes not only the problem of estimating the McMillan degree, but also of estimating further structure parameters, which determine a particular cell of any parametrization. For the last 15 years 'overlapping' parametrizations have usually been considered to be preferable for identification, because they allow identification to be started in any component, and the results to be used for selection of a better component. Our balanced parametrizations are not overlapping; on the other hand, they do give a decomposition of the manifold of systems into cells, each of which is diffeomorphic to Euclidean space. The number of cells is very large, and considerably larger than the number obtained with previously suggested parametrizations. In mitigation of this, many of the components are clearly 'non-generic', in the sense that they are associated with very special input-output properties, and initial indications are that the selection of a correct cell is not particularly difficult.

Nevertheless, there remains a problem of structure selection. As a tentative connection between this problem, our work to date, and the question of complexity, we point out that (one version of) Rissanen's Minimum Description Length principle takes account of the intrinsic geometry of the manifold of linear systems, and that we can in principle compute the relevant quantity exactly, without having to estimate it from the performance of the estimator.

Joint work with R.J.Ober and B.P.McGinnie.

Afternoon Topic: Engineering & TSA

2:00 pm	**Christopher A. Sims** University of Minnesota	Applying the likelihood principle to inference about possibly nonstationary time series

Abstract: The likelihood principle conflicts with what has become common practice in econometric analysis of possibly nonstationary time series. Either the likelihood principle needs modification, or our practices in statistical analysis and reporting do. Some of the most unsettling implications of the likelihood principle are avoided if we recognize that we seldom are dealing with a complete catalog of possible models and that computation is not free. Thus we should report absolute likelihood functions, not merely normalized likelihood functions, and should recognize that likelihood functions can be summaries of computations rather than replacements for the sample data. But this leaves unchanged the most important implications of the likelihood principle for nonstationary models – that test statistics constructed from special distribution theory conditioned on nonstationarity are unnecessary and misleading. The claim that hypothesis testing is an advantage in that it obtains approximate asymptotic theoretic semiparametric assumptions is shows to be spurious. Partial results toward a semiparametric asymptotics for the likelihood function in nonstationary models are presented.

3:00 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:15-3:45 pm	**Eric Ghysels** University of Montreal	On the economics and econometrics of seasonality
3:45-4:15 pm	**John Geweke** Duke University	Inference and forecasting for imprecisely measured deterministic nonlinear time series

Abstract: Inference and forecasting for the tent map and logicstic processes are considered for the case in which the time series is observed subject to measurement error. These simple models provide paradigms for more complex and realistic deterministic nonlinear models. Several novel findings are reported.

(1) The likelihood function is characterized by local maxima whose number is on the order of L^{2N}, where L is the Lyapunov exponent and N is sample size. Yet virtually all of the mass is concentrated in neighborhoods of a few of these points whose areas are on the order of L^{-N}. Graphical presentations indicate the influence of sample size, the Lyapunov exponent, and the severity of measurement error on the likelihood function.

(2) Steepest ascent and conventional grid methods cannot locate mass points of the likelihood function. New, adaptive grid methods developed specifically for the models succeed in doing so.

(3) The adaptive grid methods permit the construction of exact posterior densities for the unobserved signals, and predictive densities for future signals. The length of the interquartile range for signal at time t is proportional to L^{t-N}, which has important implications for sampling and forecasting.

Wednesday, July 25

Unless otherwise stated, the talks today are in Conference Hall EE/CS 3-180

9:15 am	**Coffee Break**	Reception Room EE/CS 3-176

Morning Topic: Engineering & TSA

9:30 am	**John Rust** University of Wisconsin, Madison	On the optimal retirement of older male workers
10:30 am	**Coffee Break**	Reception Room EE/CS 3-176
11-11:30 am	**Mark W. Watson** Northwestern University	Measures of fit for calibrated models

Abstract: This paper discusses measures of fit for dynamic economic models. For concreteness, consider an economic model which describes the evolution of an $n \times 1$ vector of variables x_t which is covariance stationary with autocovariance generating function (acgf) $A_x(z)$. The empirical counterparts of x_t are denoted y_t whose acgf is denoted by $A_y(z)$. The question under consideration is: Does the model generate data that "looks like" the actual data? Or, in the context of the setup described above: is $A_x(z)$ close to $A_y(z)$? This paper proposes an answer to the question by asking how much "error" has to be added to x_t so the acgf x_T+error matches the acgf of y_t. The answer depends on the assumed cross covariances between the error and x_t and y_t. This paper proposes a representation of the joint model-data-error process in which the variance of error minimized. This representation is used to construct measures of fit for the model analogous to R^2 measures used in linear regression.

11:30-Noon	**Ruey S. Tsay** University of Chicago	Model specification in multivariate time series analysis

Abstract: We propose methods for solving the problem: How to specify an appropriate yet parsimonious vector ARMA model for a given multivariate time series? By considering contemporaneous linear transformations of the vector process, we introduce the concept of ***scalar component models*** within the vector ARMA framework (a) to reveal possibly hidden, simplifying structures of the process, (b) to achieve parsimony in parameterization, and (c) to identify the exchangeable components. The simplifying structures are of particular importance in the analysis of multivariate time series because they are often not obvious from the observed data but can be used to find parsimonious models that can adequately represent the process under study. Consequently, in model specification we emphasize not only the order determination but also the detailed structure of a vector process. The analytical tool we use to search for scalar component models is a canonical correlation analysis of vector processes. The paper also discusses the identifiability of ARMA model and properties of the statistics involved in model specification. Finally, we illustrate the proposed procedures via two real examples.

Afternoon Topic: Stochastic Adaptive Control of Time-Varying Systems

Afternoon Chair: Will Gersch

1:00 pm	**Sean P. Meyn** University of Illinois, Urbana	Estimation and control of time varying systems: A Markov chain analysis of stability and performance

Abstract: We consider the problem of simultaneously controlling, and estimating the parameters of a linear time varying stochastic system. The time variations prevent an application of the classical least squares algorithm, which leads us to consider the Kalman filter based estimation algorithm which has recently been the subject of much interest.

Using recent results from the theory of Markov chains and from nonlinear control theory, we obtain geometric ergodicity of a Markovian state process. This allows a detailed description of the statistics of the output and parameter estimation error processes of the system.

In particular, we demonstrate that

(i) The Central Limit Theorem and Law of Large Numbers is valid for the stochastic processes subject to analysis;

(ii) The expectation of the square of the output and parameter estimation error processes converge to their expectation with respect to an invariant probability at a geometric rate;

(iii) The steady state expectation of the mean square parameter estimation error converges to zero as the disturbances converge to zero under a persistence of excitation condition.

The methods used in the stability proof, and in the analysis of the Markovian state process are general, and are shown to have bearing on other topics in time series analysis. In particular, it is shown that the techniques provide new results for a class of bilinear time series models.

2:00 pm	**Coffee Break**	Reception Room EE/CS 3-176

2:15-2:45 pm	**Peter E. Caines** McGill University	On the adaptive stabilization and ergodic behaviour of linear stochastic systems with jump Markov parameters

Abstract: We consider the situation where a completely observed stochastic process $y_t, t \in \mathbf{R}$, is generated by a linear stochastic system whose unobserved parameters constitute a Markov process or evolving on a finite set Θ.

As in [1, 2], we use the Wonham filter to generate the posteriori probability distribution of θ_t given the observations. These estimates are then used to generate a class of feedback control laws which are time independent. A Lyapunov function argument then establishes (subject to limits on the variations of the parameters) the boundedness of the sequence of second moments of the state process and hence, by the Beneš-Saperstone Theorem, the existence of an invariant probability measure for the state process (y_t, θ_t) of the system. Finally, we verify a Lie algebraic condition implying the hypo-ellipticity of the diffusion operator of the system process; hence we establish the uniqueness and smoothness of the invariant measure for general initial conditions.

References

1. P.E. Caines, H.F. Chen, Optimal Adaptive LQG Control for Systems with Finite State Process Parameters *IEEE Transactions on Automatic Control*, Vol. AC-30, Feb. 1985, pp. 185-189
2. H.F. Chen, P.E. Caines, On the Adaptive Stabilization of Linear Stochastic Systems with Jump Process Parameters, Proc. of 1989 *IEEE Control Systems Society Conference on Decision and Control*, pp. 742-745

This is joint work with K. Nassiri-Toussi.

2:45-3:15 pm	**Wei Ren** University of Illinois, Urbana	The convergence of parallel model adaptation schemes in the presence of colored noise

Abstract: We establish the long standing conjecture of the global convergence and parameter unbiasedness of the output error identification and adaptive IIR filtering schemes in the presence of independent additive colored noise. The algorithms considered employ a projection of the parameter estimates onto a compact convex set containing the true parameters. The colored noise is allowed to be a general nonstationary moving average noise of finite but unbounded order. An adaptive feedforward control scheme, which is a natural extension of adaptive filtering, is also discussed.

Joint work with P.R. Kumar.

3:15-3:45 pm	**H.F. Chen** Academia Sinica, Beijing	Convergence of Aström-Wittenmark's self-tuning regulator and related topics

Abstract: Let the system be described by an m-dimensional ARMAX model

$$A(z)y_n = B(z)u_{n-1} + C(z)w_n, \quad n \geq 0, \quad (zy_n = y_{n-1})$$

with unknown coefficient

$$\theta^\tau = [-A_1 \dots - A_p \; B_1 \dots B_q \; C_1 \dots C_r],$$

where p, q and r are upper bounds for orders of polynomial matrices $A(z), B(z)$ and $C(z)$ respectively.
The problem discussed here is to design adaptive control in order for the system output $\{y_n\}$ to track a given bounded reference signal $\{y_n^*\}$.
For the special case where $m = 1, y^* \equiv 0, C(z) = 1$ and B_1 is known, the self-tuning regulator proposed by Aström and Wittenmark (1973) is characterized by 1) the unknown coefficient is estimated by the recursive least squares (LS) algorithm and 2) the open loop may be unstable.
Following the well-known work of Goodwin-Ramadge-Caines there has been a great effort devoted to analysing the convergence of various adaptive trackers, which can be grouped under four classes:
1) Trackers not based on the LS or ELS algorithm but on some of their modifications;
2) Trackers based on LS or ELS but with additional stability assumption on $A(z)$;
3) Trackers using parallel estimation algorithms in addition to LS or ELS;
4) Trackers based on LS but under assumptions that $C(z) = I$ and $\{w_n\}$ is Gaussian white noise. The difficulty of this approach is that in the sample space of θ there is an exceptional set of Lebesgue measure zero which may vary with initial values of the algorithm. Whenever the system coefficient θ falls into this set, the convergence analysis fails for almost all ω.
Thus, the convergence of the ELS-based adaptive trackers, even the convergence of the original Aström-Wittenmark's self-tuning regulator has been an open problem for years. This problem is solved in the present paper.
We will use only the ELS algorithm without any modification and will work under the following standard set of conditions:
(A1) $\{w_n, \mathsf{F}_n\}$ is a martingale difference sequence with

$$\sup_{n\geq 0} E[||w_{n=1}||^\beta|\mathsf{F}_n|] < \infty \text{ a.s. for some } \beta > 2$$

and

$$\lim_{n\to\infty} \frac{1}{n}\sum_{i=1}^{n} w_i w_i^\tau \stackrel{\Delta}{=} R > 0 \text{ a.s. };$$

(A2) $C^{-1}(e^{i\lambda}) + C^{-\tau}(e^{-i\lambda}) - I > 0, \quad \forall\lambda \in [0, 2\pi]$;
(A3) $B(z)$ is of minimum phase.
Within this framework the following results are presented in this paper.
1) The Aström-Wittenmark's self-tuning tracking (y_n^* may differ from 0) is convergent and optimal. The convergence rate of tracking error is derived as well.
2) When B_1 is unknown the adaptive control is given so that the adaptive tracker is convergent and optimal.
3) Adaptive tracker with diminishing excitation technique applied gives convergence rates for both the parameter estimation error and the tracking error.

Joint work with L. Guo.

3:45-4:15 pm	**L. Guo** Academia Sinica, Beijing	Identification and adaptive control for time-varying stochastic systems

Abstract: Consider the following time-varying stochastic model

$$y_{n+1} = \phi_n^\tau \theta_n + v_{n+1}$$

where y_n, ϕ_n and v_n are the system output, regression vector and random noise, respectively.
Most of the previous work done in the area of adaptive estimation and control is concerned with the case of constant parameters, i.e. $\theta_n \equiv \theta$. In the time-varying parameter case, few concrete results are available. In this paper, we will present some precise results on both identification and adaptive control for time-varying systems.
a). **Parameter tracking.** Let $\hat{\theta}_n$ be the estimate for θ_n, which is generated by either the Kalman filtering algorithm or the lease mean squares (LMS) algorithm. It is shown that if $\{\phi_n\}$ satisfies a "conditional richness" condition, then the tracking error $E||\hat{\theta}_n - \theta_n||^4, r \in (0, s)$, is of order $O([\sigma_s]^{r/s})$, where

$$\sigma_s = \sup_{n\geq 0} E\{||v_n||^s + ||\theta_n - \theta_{n-1}||^s\}, \quad s > 0$$

The main feature of this result is that no stationarity and independence assumptions are imposed on the system signals $\{\phi_n, \theta_n, v_n\}$.

b). **Adaptive control.** We consider the case where

$$\phi_n = [y_n, \ldots, y_{n-p+1}, u_n, \ldots, u_{n-q+1}]^\tau$$

The objective is to design an adaptive control such that the output $\{y_n\}$ is bounded in an average sense. The input u_n is taken as the "certainty equivalence" minimum variance control, which is solved from

$$\phi_n^\tau \hat{\theta}_n = 0$$

where $\{\hat{\theta}_n\}$ is generated by a projected gradient algorithm with small step size. It is shown that if the unknown parameter θ_n varies slowly in some sense, then the closed-loop system in stable. Both the parameter process and the random noise are allowed to be e.g., a constant vector plus an ARMA process.

Joint work with H.F. Chen.

4:15-4:45 pm **Jian Liu** — On some nonlinear models
University of British Columbia

Abstract: Beginning with a brief introduction of nonlinear time series models, I address problems such as finite parameterization and stability, invertibility, parametric inference and identification of bilinear systems.

Thursday, July 26

Unless otherwise indicated, the talks today are in Conference Hall EE/CS 3-180

9:15 am **Coffee Break** — Reception Room EE/CS 3-176

Morning Topic: System Identification & TSA I

9:30 am **Jan C. Willems** — Continuous parametrization of linear systems
University of Groningen

Abstract: This talk describes an approach to the problem of obtaining a parametrization of the behavior of linear systems in which the continuity of the behavior corresponds to continuity in the parameters. This problem occurs both in stochastic and deterministic systems and in discrete-time and continuous-time systems. However, in this talk we will treat only discrete-time deterministic systems. Two results will be presented: First, that AR-behavioral equations (linear constant coefficient difference equations) provide a continuous parametrization of the resulting behaviors. Second, that ARNA-behavioral equations (linear constant coefficient difference equations involving both manifest and latent variables) provide a continuous parametrization if the ARMA-system is observable.

10:30 am **Coffee Break** — Reception Room EE/CS 3-176

11:00 am **Will Gersch** — Smoothness priors
University of Hawaii

Abstract: Several time series signal extraction/optimal smoothing problems are considered from a "smoothness priors" point of view. The origin of the subject is a smoothing problem posed by Whittaker (1923). It is developed here both from a stochastic regression-linear model-Gaussian disturbances framework, and a reproducing kernel Hilbert space, (RKHS), framework. We do power spectral density and transfer function estimation for stationary time series and also model nonstationary mean and nonstationary covariance times series. Also, we show the relationship of smoothness priors to spline and partial spline smoothing. Smoothness priors distributions on the model parameters are expressed either in terms of time domain stochastic difference equation or frequency domain constraints. A small number of (hyper)-parameters specify very

complex time series behavior. The critical computation is the likelihood of the Bayesian model. Examples are shown.

Afternoon Topic: Engineering & TSA

Afternoon Chair: Jim Stock

1:00 pm		OPEN FORUM

Abstract: Open Forum for general discussion of new directions of interdisciplinary research in time series analysis between economists, engineers, statisticians.

2:00 pm	**Herman K. van Dijk** Erasmus University, Rotterdam	Posterior analysis of possibly integrated time series with an application to real exchange rates and real gross national product

Abstract: In the econometric literature or time series that are possibly integrated two issues are of particular interest: model representation and the distribution of test statistics when there might be a unit root. Bayesian statistical inference for univariate time series models is considered where one of the autoregressive roots is close to or equals unity. Classical sampling theory for this type of models is hampered by the vast differences between asymptotic approximations in the stationary case and under the unit root hypothesis. Because of this dichotomy one has to decide early on in an empirical study whether a given time series is stationary or not. It is shown that a Bayesian approach allows for a smooth continuous transition between stationary and integrated time series models. A normal prior on the unconditional mean is specified with a variance that continuously increases as an autoregressive root approaches unity, in which case the variance becomes infinite.

Empirical results are presented for time series of monthly real exchange rates of eight countries and of annual real per capita GNP for 16 OECD countries.

3:00 pm	**Coffee Break**	Reception Room EE/CS 3-176
3:15-3:45 pm	**Charles H. Whiteman** University of Iowa	Unit roots in U.S. macroeconomic time series: A survey of classical and Bayesian perspectives

Abstract: The issue of whether macroeconomic time series such as GNP follow autoregressive (AR) processes which contain unit roots has several theoretical and statistical implications which have led to the development and widespread application of "unit root" tests. A stylized fact which has emerged from applications of classical unit root tests is that it is difficult to reject the null for a wide range of U.S. time series (e.g., see Nelson and Plosser (1982)).

However, in recent work (DeJong, Nankervis, Savin, and Whiteman 1989a,b) we have shown that the power of these tests against plausible trend-stationary alternatives is quite low - often much less than 50%. Further, plausible trend-stationarity hypotheses are often not rejected by the data, thus nonrejections of the unit root hypothesis must be interpreted with caution (see also Schwert (1989)).

Alternatively, in DeJong and Whiteman (1989a,b) we developed a set of Bayesian procedures designed to assess the relative plausibility of unit root and trend-stationary representations within the framework generally utilized in the Classical investigations. The procedures generate inferences which are conditional, given observed data. Posterior distributions of dominant AR roots generally indicate that trend-stationary representations are strongly supported by U.S. time series over unit root alternatives, even when strong prior support in favor of the unit root models is specified.

One drawback of the DeJong-Whiteman (1989a,b) procedures is that to maintain comparability to the Classical approaches, it was necessary to utilize a specification which made the unit root a set of measure zero in the parameter space. In DeJong-Whiteman (1990a) we adopted an alternative specification which makes the trend-stationarity specification a point on a continuum of unit root specifications. This involved differencing the data and computing the posterior distribution of the dominant moving average (MA) root – a unit MA root indicates the original series was trend-stationary, other values indicate that it contained a

unit root. These posteriors continue to suggest that (for the single series we investigated, U.S. Real GNP) the trend-stationarity specification is more plausible than the unit root specification.

Classical skeptics might argue that the posterior distributions we calculated are somehow contaminated by the tendency of MA parameter estimates to "pile up" spuriously at unity. However, in DeJong-Whiteman (1990b) we showed that while Classical sampling distributions are plagued by pileup, Bayesian posterior distributions are not.

DeJong, D.N., J.C. Nankervis, N.E. Savin and C.H. Whiteman (1989a) "Unit Root Tests or Coin Tosses for Time Series with autoregressive Errors?" Working Paper No. 89-14, Dept. of Economics, U. of Iowa.
DeJong, D.N., J.C. Nankervis, N.E. Savin and C.H. Whiteman (1989b) "Integration Versus Trend-Stationarity in Macroeconomic Time Series," Working Paper No. 89-31, Dept. of Economics, U. of Iowa.
DeJong, D.N. and C.H. Whiteman (1989a) "The Temporal Stability of Dividends and Stock Prices: Evidence from the Likelihood Function," Working Paper No. 89-3, Department of Economics, University of Iowa.
DeJong, D.N. and C.H. Whiteman (1989b), "Trends and Random Walks in Macroeconomic Time Series: A Reconsideration based on the Likelihood Principle," Working Paper No. 89-4, Department of Economics, University of Iowa.
DeJong, D.N. and C.H. Whiteman (1990a), "Trends and Cycles as Unobserved Components in U.S. Real GNP: A Bayesian Perspective," Proceedings of the American Statistical Association.
DeJong, D.N. and C.H. Whiteman (1990b), "Estimating Moving Average Parameters: Classical Pileups and Bayesian Posteriors," Working Paper No. 90-06, Department of Economics, University of Iowa.
Nelson, Charles R. and Charles I. Plosser, 1982, Trends and Random Walks in Macroeconomic Time Series: Some Evidence and Implications, Journal of Monetary Economics 10, 139-162.
Schwert, G.W. (1989), "Tests for Unit Roots: A Monte Carlo Investigation," Journal of Business and Economic Statistics 7:147-158.

Joint work with David N. DeJong.

3:45-4:15 pm **Peter Schotman** Erasmus University — Excess volatility and excess smoothness of long term interest rates

Abstract: The paper re-examines volatility tests of the expectations model of the term structure of interest rates. The sensitivity of the tests with respect to assumptions on the presence of unit roots is investigated in particular. The restrictions of the expectations model are derived in a general multivariate MA representation of the time series process of interest rates. The paper employs Bayesian techniques to compute the distributions of the test statistics efficiently and exactly. Three different tests of the restrictions implied by the expectations model are developed: (1) a test conditional on stationarity of the bivariate process of long and short term interest rate time series; (2) a test conditional on co-integration between long and short rates; (3) a test that takes account of the uncertainty with regard to the presence of unit roots.

4:15-4:45 pm **A. Marcet & R. Marimor** Carnegie Mellon U. & U. of Minnesota — Communication, commitment and growth

Friday, July 27

Unless otherwise indicated, the talks today are in Conference Hall EE/CS 3-180

9:15 am **Coffee Break** — Reception Room EE/CS 3-176

Morning Topic: Engineering & TSA

Morning Chair: John Geweke

9:30 am **Ron Gallant & George Tauchen** N. Carolina St. & Duke Universities — Nonlinear time series analysis: Estimation and simulation

Abstract: We describe a method of nonlinear time series analysis suitable for nonlinear, stationary processes whose one-step-ahead conditional density depends on a finite number of lags. Such a density can be represented as a Hermite expansion. Certain parameters of the expansion can be set to imply sharp restrictions on the process such as a pure VAR, a pure ARCH, a nonlinear process with homogeneous innovations, etc.

The model is fitted using maximum likelihood procedures on a truncated expansion together with a model selection strategy that determines the truncation point. The estimator is consistent for the true density with respect to a strong norm. The norm is strong enough to imply consistency of evaluation evaluation functionals and moments of the conditional density. We describe a method of simulating from the density. Simulation can be used for a great variety of applications. In this paper, we give special attention to using simulations to set sup-norm confidence bands. Software, in the form of a 5-1/4 2S/2D DOS formatted diskette, is available from the authors. An appendix to this paper describes its use.

10:30 am	**Coffee Break**	Reception Room EE/CS 3-176

11-11:30 am	**James Stock** Harvard University	Deciding between I(1) and I(0)

Abstract: A class of procedures is developed to distinguish time series that are integrated of order zero (I(0)) from those that are integrated of order one (I(1)), where I(0) and I(1) are defined nonparametrically in terms of weak properties of the Wold representation of the process. These procedures entail the evaluation of the likelihood of certain statistics, first under the hypothesis that the series is I(0), then under the I(1) hypothesis. The asymptotic distribution of these statistics does not depend on the nuisance parameters, although it does depend on whether the process is I(1) or I(0). Asymptotically, the I(0) and I(1) distributions diverge, so the likelihood ratio (for these statistics) provides a consistent basis for deciding whether the process is I(1) or I(0). Alternatively, a posterior odds ratio can be computed, where the prior distribution needs to be defined only in terms of the points "I(0)" and "I(1)", rather than in terms of parametric specifications within the class of I(0) and I(1) processes.

11:30-Noon	**Fallaw Sowell** Carnegie Mellon University	Modeling the long run behavior of time series

Abstract: Several researchers have recently been concerned with estimating the low frequency or long run behavior of economic time series. The ARMA models, often used in these studies, are not well suited to capture the long run behavior of a time series. A more appropriate choice is the fractionally integrated ARMA model. Its special long run characteristics are reviewed and contrasted with measures of long run behavior that are based on the spectral density at frequency zero. As an application of this approach, the long run behavior of post war real GNP is investigated.

Afternoon Topic: System Identification & TSA II

1:00 pm	**Manfred Deistler** Technische U. Wien, Austria	Identification of dynamic systems from noisy data

Abstract: Linear dynamic errors-in-variables (or factor-) models in the framework of stationary processes are considered. The noise process is assumed to have a diagonal spectral density. We analyse the relation between the (population) second moments of the observations and the system- and noise characteristics; of particular interest are the number of equations (or the number of factors) and a description of the set of all systems compatible with the second moments of the observations. Special emphasis is put on the cases of a single equation and of a single factor. The problems considered arise in the context of identification and precede estimation.

2:00 pm	**Coffee Break**	Reception Room EE/CS 3-176
2:15-2:45 pm	**Tze L. Lai** Stanford University	Asymptotically efficient recursive identification algorithms in time series models and linear stochastic systems
2:45-3:15 pm	**D. Guégan** U. Paris-Nord, Villetaneuse	Identification and forecasting in non linear stochastic processes

Abstract: For some non linear stochastic processes $(X(t))$ (bilinear models, ARCH models, state affine polynomial models) we investigate problems concerning:

from one part the different methods of identification. (Cumulants of some order, corner method, Glasbey statistic, canonical analysis), and,
from another part the analytical expression of the non linear predictor $E[X(t+h)|X(s), s \leq t]$, its error and the variance of its error. Developments concerning the confidence intervals for the last predictor is given from two different methods.

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CURRENT IMA PARTICIPANTS

POSTDOCTORAL MEMBERS FOR 1989-90 PROGRAM YEAR

NAME	PREVIOUS/PRESENT INSTITUTION
H. Scott Dumas	SUNY, Albany
Mohamed Elbialy	University of Cincinnati
Michael S. Jolly	Princeton University
Maciej Krupa	University of Houston
Stephane Laederich	Boston University
Debra Lewis	Cornell University
Kening Lu	Georgia Institute of Technology
Mary Silber	UC, Berkeley
Matthew W. Stafford	Loyola University
Mary Lou Zeeman	MIT

TIME SERIES PROGRAM AND SHORT TERM VISITORS IN RESIDENCE

Florin Avram	Northeastern University	Jul 9 - 15
Babs Ayeni	3M	Jul 1-7, 25-27
Jimmy Baikovicius	*McGill University*	Jul 2 - 29
Marilena Barbieri	U. Degli Studi di Roma	Jul 3 - 28
John Baxter	University of Minnesota	
Karim Benhenni	Northern Illinois University	Jul 14 - 21
Jan Beran	Texas A&M University	Jul 8 - 15
R.J. Bhansali	University of Liverpool	Jul 15 - 28
J.A.R. Blais	University of Calgary	Jul 1 - 26
P.M. Bleher	Keldysh Inst. App. Math, Moscow	Jul 7 - 15
Mary Ellen Bock	National Science Foundation	Jul 1-8, 14-22
Jay Briedt	Colorado State University	Jul 1 - Jul 27
David R. Brillinger	UC Berkeley	Jun 30 - Jul 6
Peter J. Brockwell	Colorado State University	Jul 15 - 22
Lyndon Brown	University of Illinois, Urbana	Jul 24 - 27
Peter E. Caines	McGill University	Jul 1-9, Jul 25-28
Quanwei Cao	University of Chicago	Jul 1 - 7
Ed Carlstein	University of North Carolina	Jul 16 - 20
Martin Casdagli	Los Alamos Nat. Labs.	Jul 1 - 27
K.S. Chan	University of Chicago	Jul 1 - 6
Ngai Hang Chan	Indiana University	Jul 24 - 28
Han Fu Chen	Academia Sinica, Beijing	Jul 14 - 28
Rong Chen	Texas A&M University	Jul 1-6, 15 - 20
Byong Seon Choi	Yonsei University	Jul 2 - 27
Renata Cioczek	Boston University	Jul 7 - 21
H. Cohn	University of Melbourne	Jul 1 - 13
Nuno Crato	University of Delaware	Jul 1 - 28
Jonathon D. Cryer	University of Iowa	Jul 15 - 20
Richard A. Davis	Colorado State University	Jul 15 - 22

Yuri A. Davydov	Leningrad State University	Jul 1 - 18
Herold Dehling	Groningen	Jul 2 - 20
M. Deistler	Technische U. Wien, Austria	Jul 20 - 28
Kevin Dooley	University of Minnesota	Jul 9, 16
William Dunsmuir	Bond University	Jul 2 - 26
Katherine B. Ensor	Rice University	Jul 15 - 27
Ludwig Fahrmeir	Universitat Regensburg	Jul 14 - 21
Robert V. Foutz	VPI&SU	Jul 14 - 20
Avner Friedman	IMA	
Wayne Fuller	Iowa State University	Jul 15 - 20
A. Ronald Gallant	North Carolina State University	Jul 21 - 27
Seymour Geisser	University of Minnesota	
Joseph Gardiner	Michigan State University	Jul 26 - 27
Laszlo Gerencser	McGill University	Jul 1 - 28
W. Gersch	Naval Postgraduate School	Jul 21 - 27
John Geweke	Duke University	Jul 23 - 27
Eric Ghysels	University of Montreal	Jul 23 - 25
G.B. Giannakis	University of Virginia	Jul 1 - 9
A. Gombani	LADSEB - CNR, Padova, Italy	Jul 22 - 27
Victor Goodman	Indiana University	Jul 9 - 12
Patricia Grambsch	University of Minnesota	Jul 3 - 28
Charles A. Greenhall	Jet Propulsion Lab.	Jul 9 - 13
D. Guégan	Universite Paris-Nord, Villetaneuse	Jun 30-Jul 11, Jul 15-28
Lei Gou	Academia Sinica, Beijing	Jul 14 - 28
M. Guo	Worcester Polytechnic Inst.	Jun 30 - Jul 6
Ben Hanzon	Free University of Amsterdam	Jul 16 - 28
Keith Helmlinger	University of Minnesota	Jul 2 - 27
M.A. Herrero	U. Complutense	Jun 25 - Jul 22
A.J. Heunis	University of Waterloo	Jul 23 - 27
M. Hinich	University of Texas	Jul 1 - 8
Hwai-Chung Ho	Natl. Sun Yat-Sen U.	Jul 3 - 17
Clifford M. Hurvich	New York University	Jul 9 - 20
Naresh Jain	University of Minnesota	
Tae Jeon	Wayne State University	Jul 1 - 15
Don Johnson	Rice University	Jul 9 - 12
Z. Jurek	Wayne State University	Jul 6 - 13
Myron Katzoff	Nat. Ctr. Health Stats.	Jul 1 - 27
Mos Kaveh	University of Minnesota	
Michael Keane	Delft U. of Technology	Jul 7 - 14
B. Kedem	University of Maryland	Jul 16 - 20
Jim Kuelbs	University of Wisconsin	Jul 9 - 13
P. Kulkarni	University of South Alabama	Jul 15 - 21
Pat Kumar	University of Minesota	
Michael Lacey	Indiana University	Jul 7 - 13
Olivier Lafitte	Ecole Nationale Sup.	Jul 19 - 23
T.Z. Lai	Stanford University	Jul 23 - 27
Bruce Lee	University of Minnesota	Jul 17 - 20
Jack Lee	Bellcore	Jul 15 - 20
Yi-teh Lee	Bellcore	Jul 17 - 21
P.A.W. Lewis	Naval Postgraduate School	Jul 2 - 7
Keh-Shin Lii	UC Riverside	Jul 1 - 10
Anders Lindquist	Royal Inst. of Tech., Stockholm	Jul 22 - 26
Jian Liu	University of British Columbia	Jul 2 - 27

Shu-ing Liu	National Central U., Taiwan	Jul 15 - 27
Greta M. Ljung	MIT	Jul 14 - 20
Silvia Lopez	University of Maryland	Jul 15 - 22
Cornelius A. Los	Nomura Research Inst., New York	Jul 22 - 28
Jan M. Maciejowski	Cambridge University	Jul 23 - 29
Peter Major	Hungarian Academy of Sciences	Jul 3 - 20
Jovan Malisic	U. of Beograd	Jun 27 - Jul 28
Benoit Mandelbrot	IBM	Jul 8 - 13
V. Mandrekar	Michigan State University	Jul 1 - 7
Albert Marcet	Carnegie Mellon University	Jul 22 - 30
Andrew McDougall	Rutgers University	Jul 14 - 28
Eddie McKenzie	University of Strathclyde	Jul 1 - 13
Laurie Meaux	University of Arkansas	Jul 1 - 8
J.M. Mendel	USC	Jul 4 - 6
Sean Meyn	Australian National University	Jul 20 - 26
A.G. Miamee	Hampton University	Jul 15 - 25
Willard Miller, Jr.	IMA	
Stefan Mittnik	SUNY Stony Brook	Jul 1 - 28
Luciano Molinari	Children's Hospital, Zurich	Jun 30-Jul 7, Jul 14-21
John Morrison	University of Delaware	Jul 1 - 31
Neerchal K. Nagaraj	University of Maryland	Jul 2 - 10
Sanjeev Naik	University of Illinois, Urbana	Jul 23 - 27
Dankit K. Nassiuma	University of Manitoba	Jul 15 - 27
C.L. Nikias	Northeastern University	Jul 1 - 4
George O'Brien	York University, Ontario	Jul 7 - 14
Stephen Orey	University of Minnesota	
T. Ozaki	Inst. of Stat. Math., Tokyo	Jul 1 - 28
Adrian Papamarcou	University of Maryland	Jul 7 - 13
George Papanicolaou	Courant Institute	Jun 30 - Jul 5
Emanuel Parzen	Texas A&M University	Jul 2 - 27
Michael Parzen	Harvard University	Jul 12 - 18
Joseph D. Petruccelli	Worcester Polytechnic Inst.	Jul 1 - 8
Jacques Peyriere	Universite de Paris Sud, Orsay	Jul 8 - 14
Percy Pierre	Prairie View A&M University	Jul 2 - 6
German Pliego	Purdue University	Jul 1 - 7
Dimitris Politis	Stanford University	Jul 1 - 7
Mohsen Pourahmadi	Northern Illinois University	Jul 1 - 20
Paul Pukit	DAINA	Jul 16 - 16
Madan L. Puri	Indiana University	Jul 15 - 22
James Ramsey	New York University	Jul 17 - 20
M.B. Rao	North Dakota State University	Jul 1 - 6
T. Subba Rao	University of Manchester	Jul 1 - 13
R. Ravikanth	University of Illinois, Urbana	Jul 23 - 27
Gregory Reinsel	University of Wisconsin	Jul 16 - 20
Wei Ren	University of Illinois, Urbana	Jul 17 - 27
Peter Robinson	London School of Economics	Jul 13 - 17
Juan Romo	Universidad Compluteuse	Jul 16 - 28
Murray Rosenblatt	UC San Diego	Jul 1 - 10
Phil Rothman	New York University	Jul 1 - 6
Kalyan Roy	Indiana University	Jul 16 - 20
John Rust	University of Wisconsin	Jul 24 - 26
H. Salehi	Michigan State University	Jul 15 - 19
V.A. Samaranayake	University of Missouri, Rolla	Jul 1 - 28

Gennady Samorodnitsky	Cornell University	Jul 7 - 13
Tim Sauer	George Mason University	Jul 2 - 6
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Peter Schotman	Erasmus University	Jul 2 - 28
Eric Sheppard	University of Minnesota	Jul 16 - 19
Robert Shumway	UC Davis	Jul 15 - 18
J. Sidorowich	UC Santa Cruz	Jul 1 - 13
Christopher A. Sims	University of Minnesota	Jul 23 - 27
Milton Sobel	UC Santa barbara	Jul 16 - 18
Gerald Sobelman	University of Minnesota	Jul 2 - 27
Victor Solo	Johns Hopkins University	Jul 9 - 13
Fallaw Sowell	Carnegie Mellon University	Jul 22 - 27
James Stevens	Naval Postgraduate School	Jul 1 - 5
James Stock	UC Berkeley	Jul 23 - 27
David Stoffer	University of Pittsburgh	Jul 14 - 20
Shan Sun	Indiana University	Jul 15 - 22
T.C. Sun	Wayne State University	Jul 7 - 13
Mario Taboada	Cornell University	Mar 21 - Aug 10
Allen Tannenbaum	University of Minnesota	
Murad Taqqu	Boston University	Jul 8 - 17
George Tauchen	Duke University	Jul 22 - 26
G. Terdik	University of Arkansas	Jul 1 - 8
David Terman	Ohio State University	Jul 10 - 15
Norma Terrin	Carnegie Mellon University	Jul 8 - 20
Ahmed Tewfik	University of Minnesota	Jul 2 - 27
Lori A. Thombs	University of South Carolina	Jul 15 - 27
Howell Tong	University of Kent	Jul 2 - 7
Kinh Truong	University of North Carolina	Jul 14 - 20
Ruey Tsay	University of Chicago	Jul 19 - 25
Jitendra K. Tugnait	Auburn University	Jul 1 - 6
John W. Tukey	Princeton University	Jul 15 - 18
Alvaro Tuzman	University of Minnesota	Jul 9 - 31
Zsuzsanna Vago	Tech. U. of Budapest	Jul 1 - 27
Herman van Dijk	Erasmus University, Rotterdam	Jul 19 - 27
Wim Vervaat	Catholic University, Nijmegen	Jul 7 - 14
Mark Watson	Northwestern University	Jul 23 - 26
Ed Waymire	Oregon State University	Jul 1 - 14
C.Z. Wei	University of Maryland	Jul 23 - 28
Charles Whiteman	University of Iowa	Jul 24 - 27
Jan C. Willems	Groningen University	Jul 23 - 27
Akiva Yaglom	Acad. Sciences, USSR	Jul 2 - 20
Yoshihiro Yajima	University of Tokyo	Jul 6 - 28
George Yin	Wayne State University	Jul 22 - 30
Scott Zeger	Johns Hopkins University	Jul 12 - 19
Nien Fan Zhang	Shell Development Co.	Jul 23 - 27
Guofu Zhou	Duke University	Jul 22 - 27

Institute for Mathematics and its Applications
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—IMA

June 27, 1991

Dr. Neil L. Gerr
Mathematical Sciences Division
Department of the Navy
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217

RE: GRANT #: N00014-90-J-1658

Dear Dr. Gerr:

I am enclosing our final technical report for the grant entitled " Radar/Sonar and Time Series Analysis" grant number N00014-90-J-1658.

3 copies of the proceedings volume *Radar/Sonar, Part I* are also enclosed. The remaining volumes *Radar/Sonar, Part II* and the *Time Series Analysis* volumes are still in production and will be sent to the Office of Naval Research upon completion.

Sincerely yours,

Willard Miller, Jr.,
Associate Director

enclosures: Final Technical Report
and 3 copies of proceedings volume
WM:kas