International Workshop on 2025/7/12

Advances in biomedical signal processing, from theory to application

1 Title & abstract

1. Ronen Talmon, Technion EE

   • Title: Enhanced Matrix Pencil Method for Noisy Signals Using Structured Modes

   • Abstract: Consider the problem of detecting the number of complex exponentials and estimating their parameters in a noisy signal. This longstanding problem in signal processing has been addressed using various techniques, e.g., Prony's method, ESPRIT (Estimation of Signal Parameters via Rotational Invariance Techniques), and MUSIC (Multiple Signal Classification). We focus on the matrix pencil (MP) method, presented by Hua and Sarkar in 1990, which has gained popularity for its effectiveness in cases involving closely-spaced frequencies where other methods struggle. In the noiseless case, the MP method provably yields perfect detection and estimation. However, in the presence of noise, there is no theoretical support, and common practice relies on heuristics that often yield subpar performance. In this talk, we will present a new analysis that extends the theoretical foundation of the MP method to noisy conditions. Specifically, our results reveal that the MP modes encompass an informative structure that enables us to propose a new detection and estimation algorithm that leverages these modes. This approach contrasts with existing heuristics that typically rely exclusively on the MP singular values. We will demonstrate the performance of the proposed method through simulations, showing its significant advantages over the existing methods.

2. Gi-Ren Liu, NCKU, mathematics

   • Title: Convergence Rate Analysis in Limit Theorems for Nonlinear Functionals of the Second Wiener Chaos

   • Abstract: In this talk, we would like to discuss the asymptotic behavior of the analytic wavelet transform applied to the squared envelope of Gaussian processes. Our focus is on how the long-memory parameter of the input process influences the scaling limits and its convergence rate. Specifically, for input processes with a long-memory parameter below $1/2$, the squared modulus of the analytic wavelet transform, after appropriate rescaling, converges to a combination of the second and fourth Wiener chaos. For the long-memory parameter exceeding $1/2$, the limit is a chi-distributed random process. We will discuss how these differences arise. The convergence rates are quantified by the Kolmogorov and Wasserstein metrics. A notable transition in behavior of the convergence rate occurs at the critical long-memory parameter of $1/2$. The results are derived using tools from the Malliavin calculus and Stein's method.

3. Zhou Zhou, UToronto, stat

   • Title: Optimal Tuning Parameter Selection in Heteroscedasticity and Autocorrelation Robust Inference

   • Abstract: The selection of a block size/window size/bandwidth parameter is universal and important in various Heteroscedasticity and Autocorrelation Robust (HAR) inference problems. Most current proposals for choosing this parameter are ad hoc without theoretical justification of their performance or optimality. In this talk, we shall investigate the asymptotic bias and variance of a fundamental HAR procedure for a general class of piecewise locally stationary time series. As a result, an easy to implement and asymptotically optimal tuning parameter selection algorithm is proposed. Our investigation also reveals that analogous tuning parameter selection algorithms for stationary time series are biased above for non-stationary time series.

4. Yu-Ting Lin, VGHTPE

   • Title: Cardiovascular signal data analysis for clinical anesthesia and surgery

   • Abstract: Human body performs sophisticated biological functions. Through physical connections and physiological mechanisms, the cardiovascular system interacts with numerous organ functions. These interactions are further complicated by modern medical treatment, including the surgery. Cardiovascular signal data analysis grant insight into the human body on every moment for each patient, only if we have practical mathematical models to develop algorithms. Today we will focus on these biological interactions as the foundation of modeling.

5. Marcelo Colominas, CONICET BME

   • Title: Non-stationay Oscillatory Signal Modeling

   • Abstract: In this talk we will revisit existing models for non-stationary oscillatory signals, with special emphasis on the biomedical field. We will start with the âĂIJAdaptive Non-Harmonic ModelâĂİ (ANHM), and then move to the latest developments. In particular, we will visit the âĂIJShape-Adaptive Mode DecompositionâĂİ (SAMD) that allows for time-varying waveforms, and then on a âĂIJFully AdaptiveâĂİ version of it that gives more versatility. We will finish the talk by discussing models for âĂIJspikyâĂİ signals, and this would take us into the manifold learning domain.

6. Jenn-Nan Wang, NTU math

   • Title: Quantitative approximation theorems for scattering neural operators

   • Abstract: In this work, I would like to discuss the learning of a nonlinear operator for the scattering problem based on neural operator architectures. In most inverse scattering problems, the forward operator mapping from the refractive index to the far-field pattern is commonly used measurement. Many numerical methods for constructing the refractive index from the knowledge of the far-field pattern need to evaluate the forward operator, which involves solving PDEs and taking asymptotics. Such a procedure is time consuming and not effective. It is therefore a favorable practice to construct a surrogate to replace this forward operator. The main purpose of this paper is to demonstrate that, under certain conditions, the "parametric complexity" of neural scattering operators grows at most logarithmically with respect to the desired accuracy. This result makes the application of these neural operators rather promising in practice. This talk is based on joint works with Takashi Furuya.

7. Govind Menon, Brown math

   • Title: Manifold learning and the Nash embedding theorems

   • Abstract: The modern study of the isometric embedding problem for Riemannian manifolds is founded on Nash's pioneering work in 1954 and 1956. In the past ten years, there has been a renewal of interest in these theorems in light of unexpected applications and connections to turbulence and machine learning. These connections have motivated us to revisit these theorems from probabilistic foundations.

8. Stefan Steinerberger, UW math

   • Title: Stochastic Gradient Descent for Linear Systems

   • Abstract: Stochastic Gradient Descent needs no introduction. A particular nice setting in which one can study this fundamental idea is the problem of minimizing $\|Ax - b\|^2$, arguably the most important problem out there. We'll discuss a nice old method by Stefan Kaczmarz from the 1930s, how it gained momentum with a brilliant randomization by Strohmer & Vershynin and how this has given rise to a very beautiful marriage between classical Euclidean geometry and Probability Theory. A great many open problems remain and will be discussed.