FUSION 2023 - Tutorial Proposal

1. **Title of the proposed tutorial:** **"Estimation and Tracking of Graph Signals"**
2. **Length of the tutorial:** Half-day
3. **The intended audience and prerequisites for the attendees' background knowledge:**
   The intended audience is graduate students, postdocs, and PIs with engineering backgrounds. Recommended prerequisites for this tutorial are probability theory, linear algebra, and digital signal processing. Knowledge of statistical signal processing would be helpful.
4. **A description of the tutorial, including the learning objectives and a short summary of the material to be presented.**

Graphs are fundamental mathematical structures that are widely used in various fields for network data analysis to model complex relationships within and between data, signals, and processes. In particular, graph signals arise in many modern applications, leading to the emergence of the area of graph signal processing (GSP) in the last decade. GSP theory extends concepts and techniques from traditional digital signal processing (DSP) to data indexed by generic graphs, including the graph Fourier transform (GFT), graph filter design, and sampling and recovery of graph signals. While the early research in this field has focused on purely *deterministic* settings, this tutorial aims to develop *statistical* signal processing (SSP) methods and bounds for GSP, named graph SSP (GSSP) theory. The tutorial focuses on estimating graph signals, which has numerous applications in various fields, including computer science, social science, sensor networks, energy systems, transportation, and biology. Furthermore, the tutorial will emphasize the development of GSP estimation methods for power system monitoring, serving as a *practical* test case while also enriching *theoretical* GSSP tools. This smart grid application is vital for addressing climate change, advancing energy solutions, and promoting societal well-being.

Tutorial outline

I. Introduction to GSP: Networks and graph signal representation, adjacency and Laplacian matrices, Graph Fourier Transform, graph spectrum, and graph filters

II. Graph total variation and its uses for graph signal estimation:
   a. Laplacian-based regularized weighted least squares (WLS) estimation
   b. Bad data detection based on graph total variation.
   c. Application: state estimation and detection of false data injected (FDI) attacks in power systems

III. Bayesian estimation of graph signals:
   a. Problem formulation, model assumptions, and classical Bayesian approaches
   b. GSP-linear minimum mean squared error (GSP-LMMSE) estimator: development, properties, and special cases.
   c. GSP-widely-linear MMSE estimator for improper complex-valued setting: development, properties, and special cases.
   d. Nonlinear GSP maximum-a-posteriori (GSP-MAP) estimator development, properties, and special cases.
   e. Model-based learning: Generative Versus Discriminative Data-Driven Graph Filtering of Random Graph Signals
   f. Application: state estimation in power systems

IV. Tracking of graph signals - GSP-extended Kalman filter for dynamic signal estimation

V. Performance bounds:
   a. Non-Bayesian biased Cramér-Rao bound (CRB) for Laplacian-based regularized estimation.
   b. Non-Bayesian constrained CRB for the estimation of graph signals.
   c. The use of the graph CRBs for sampling graph signals.

VI. Discussion of related topics and extensions (only highlights, as time permits):
   a. Identification of edge disconnections in networks based on graph filter representation
   b. Graph smoothness validation
   c. Laplacian learning for graph signal estimation
   d. Graph blind source separation.
   e. Additional applications in energy management systems

VII. Conclusion and Future Directions

5. **Biographical sketch(es) of the instructor(s) including previous lecture and tutorial experience.**

Prof. Tirza Routtenberg,

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2) Visiting Professor for Distinguished Teaching, Princeton, NJ 2022-2023

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Tirza Routtenberg received the B.Sc. degree (magna cum laude) in biomedical engineering from the Technion Israel Institute of Technology, Haifa, Israel, in 2005, and the M.Sc. (magna cum laude) and Ph.D. degrees in electrical engineering from the Ben-Gurion University of the Negev, Beer-Sheva, Israel, in 2007 and 2012, respectively. She was a Postdoctoral Fellow with the School of Electrical and Computer Engineering, Cornell University, in 2012-2014. Since October 2014, she has been a faculty member at the School of Electrical and Computer Engineering and Ben-Gurion University of the Negev, Beer-Sheva, Israel. Her research interests include signal processing in smart grids, statistical signal processing, estimation and detection theory, and signal processing on graphs. She is an associate editor of IEEE Transactions on Signal and Information Processing Over Networks and of IEEE Signal Processing Letters, as well as a member of the IEEE Signal Processing Theory and Methods Technical Committee. She was a recipient of the Best Student Paper Award at the International Conference on Acoustics, Speech and Signal Processing (ICASSP) 2011, in IEEE International Workshop on Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP) 2013 (coauthor), in ICASSP 2017 (coauthor), and in IEEE Workshop on Statistical Signal Processing (SSP) 2018 (coauthor). She was awarded the Negev scholarship in 2008, the Lev-Zion scholarship in 2010, the Marc Rich foundation prize in 2011, and the Toronto prize for excellence in research in 2021.

In terms of lecturing and education, Tirza is an SPS Education Center Editorial Board Member on the IEEE Signal Processing Society Education for 2022 –2025. She is a member of the IEEE Signal Processing Theory and Methods (SPTM) Technical Committee, 2018-2023. In addition, she is a member of the Steering Committee of the international IEEE SPS Mentoring Experiences for Underrepresented Young Researchers (ME-UYR). Tirza was the Publication co-chair of EUSIPCO 2022 in Belgrade and the Tutorial Chair of IEEE SAM 2022 in Trondheim. Finally, she has been appointed The William R. Kenan, Jr. Visiting Professorship for Distinguished Teaching for appointments for the academic year 2022-2023 at Princeton University.