Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Signal and Information Processing Laboratory (ISI)

Annual Report 2022

Signal and Information Processing Laboratory
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Foreword

by Amos Lapidoth

By the beginning of 2022, the pandemic was nearly behind us. Nevertheless, with great regret, we had to cancel the 2022 International Zurich Seminar, because many of our international colleagues were still under heavy travel restrictions. Needless to say, with the technical program in place and the plenary speakers all confirmed, calling the conference off was no fun. But we bounced back and ended up with a great year.

Visiting us from abroad were Martin Hänggi, Roxana Smarandache, Ligong Wang and Michèlle Wigger. Interacting with them personally and scientifically was great fun and most fruitful.

We were delighted to welcome Tianyang Wang, Yunpeng Li, and Baohua Ni who began their Ph.D. studies, and wistfully saw Robert Graczyk, Boxiao Ma, and Patrick Murer leave the nest with their freshly minted Ph.D. degrees. We wish them all the very best.

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1 People

Professors:	Amos Lapidoth Hans-Andrea Loeliger
Senior Scientist:	Stefan Moser
Postdocs:	Hampus Malmberg Ran Tamir Reto Wildhaber
Research Assistants / PhD Students:	Hugo Aguettaz Robert Graczyk Raphael Keusch Yunpeng Li Boxiao Ma Patrick Murer Baohua Ni Elizabeth Ren Guy Revach Tianyang Wang Yiming Yan
Technical Staff:	Patrik Strebel
Secretaries:	Simone Ammann Olivia Bärtsch

2 Teaching

2.1 Regular Courses

- *Discrete-time and Statistical Signal Processing*, Prof. Loeliger (Bachelor & Master)
- *Communication and Detection Theory*, Prof. Lapidoth (Bachelor)
- *Information Theory I*, Prof. Lapidoth (Master)
- *Introduction to Estimation and Machine Learning*, Prof. Loeliger (Bachelor & Master)
- *Advanced Signal Analysis, Modeling, and Machine Learning*, Prof. Loeliger (Master)
- *Algebra and Error Correcting Codes*, Prof. Loeliger (Master)

Courses by External Lecturers

- *Acoustics I*, Dr. Kurt Heutschi (Master)
- *Acoustics II*, Dr. Kurt Heutschi und Dr. Reto Pieren (Master)
- *Analog Signal Processing and Filtering*, Dr. Hanspeter Schmid (Master)

2.2 Lab Courses

- Fachpraktika, Hugo Aguettaz
- *Electronic Circuits and Signals Exploration Laboratory,* Hampus Malmberg & Raphael Keusch

2.3 Student Projects

Student(s)	Title	Supervisor(s)
Semester Projects, Spring Term 2022		
Mehdi Bakka	*Fetal Electrocardiogram (FECG) Denoising*	Guy Revach
Zunnoor Fayya Awan	*Outlier Detection in State Estimation via Hypothesis Testing*	Guy Revach
Oliver Hüsser	*Hybrid Modelling in Control for Systems Described by Partially Known State Space Models*	Guy Revach Nir Shlezinger
Jiayi Wu	*Estimating Time-varying Channels with a Kalmar Filter*	Guy Revach
Lukas Hollinger	*Kalman Filtering with High-Dimensional Non-Linear Observations - Two-Step Approach with Application to RF-Localization in Near Field*	Guy Revach
Semester Projects, Fall Term 2022		
Stefan Schucker	*Generation and Classification of Outdoor Traffic Sounds Using Machine Learning* Techniques	Reto Pieren
Leo Malli	*Phase Unwrapping Using Binarizing NUV Priors*	Hans-Andrea Loeliger Raphael Keusch Guy Revach
Alessio Lukaj	*Nonograms and Iterative Constraints Propagation*	Hugo Aguettaz Hampus Malmberg Raphael Keusch
Arsim Dzambazoski	*Calibrating a Control Bounded Analog-to-Digital Converter in Rust*	Hampus Malmberg
Tongyu Lu	*Note-level Automatic Music Transcription through Single-chord Fourier Approximation (SCFA)*	Guy Revach Nir Shlezinger
Colin Dirren	*Robustness Analysis of KalmanNet for a Non-linear Gerstner Waves Model*	Guy Revach Sotiris Aspragkathos
Johannes Schading	*Which is the Worst Additive Noise on the Poisson Channel*	Ligong Wang

Master Projects, Spring Term 2022

Mohamed Ibrahim	*Airflow and Pressure Analysis and Leak Detection of Pneumatic Systems*	Elizabeth Ren Lennard Schwidurski
Benjamin Wolff	*Sequential Sampling for Anomaly Detection*	Guy Revach
Ke Zhang	*Kalman Smoothing of Non-time-invariant Signals with Partial Information-Combining With Local Model Fit*	Guy Revach
Damiano Steger	*Tracking of a Dynamical System from Visual Observations*	Guy Revach
Marko Tosic	*Exploring NU Priors*	Hans-Andrea Loeliger Raphael Keusch
Haoran Deng	*KALMANBOT: KalmanNet and Bollinger Bands based Learned Trader for Pairs Trading*	Guy Revach

Master Projects, Fall Term 2022

Aron Szakacs	*Application of Multitone Signalling to Wireline Systems*	Armin Tajalli Hans-Andrea Loeliger
Timur Locher	*Hierarchical Filtering With Online Learned Priors For ECG Denoising*	Guy Revach
Gaspard Ulysse Fragnière	*Generative Adversarial Networks for the Generation of Microphone Array Data*	Adam Kujawski

3 Research

3.1 General Research Areas

Information Theory and Error Correcting Codes

- Multi-user Information Theory
- Network Coding
- Information Measures and Applications
- Robust Communications
- Communications in the Presence of Feedback
- Optical Channels
- Error Correcting Codes

Signal Processing

- Factor Graphs and State-Space Methods
- Recursive Local Model Fitting
- NUV Priors
- Imaging and Tomography
- Model-based Deep Learning
- “Neural” Computation and Memorization
- Analog-to-Digital Conversion

3.2 Current Research Topics with Prof. Lapidoth

Information measures with Applications

Over the years, starting with the pioneering work of Alfréd Rényi (1921 – 1970), numerous attempts were made at generalizing the classical information measures such as Entropy, Kullback-Leibler Divergence, and Mutual Information. In a flurry of recent activity, important new roles have emerged for measures such as Rényi Entropy, Rényi Divergence, f-divergence, Arimoto's Mutual Information, Sibson's Information Radius and others. We study the applications of these and other measures for guessing, hypothesis testing, error exponents, task encoding, large deviations, and portfolio theory.

Encoder-Assisted Communications

Our group has recently proposed "flash helping" as an efficient technique for producing a rate-limited description of the noise corrupting a channel. Based on this technique, we proposed a coding technique for communicating over additive noise channels where a helper observes the noise and can describe it to the encoder over a noise-free rate-limited bit pipe. The technique is applicable irrespective of whether the helper observes the noise causally or noncausally. On the single-user channel of general noise, the rate it achieves is the sum of the channel's capacity without a helper and the rate of the bit pipe. For gaussian noise and under an average-power constraint, it is optimal. Analogous results are derived for the additive noise multiple-access channel and the single-user Exponential channel. The approach is applicable also in some (noncausal) discrete settings, as demonstrated on the discrete modulo-additive noise channel.

Zero-Error, Erasures-Only, and List-Size Capacities

The Shannon capacity of a noisy channel is the supremum of all the rates that are achievable in the sense that they allow communication with arbitrarily small, but positive, probability of error. But this is not the only capacity of interest. The zero-error capacity allows no errors at all, and is typically smaller than the Shannon capacity. The erasures-only capacity does not allow the decoder to err, but it does allow it to declare "I don't know," as long as it does so with probability tending to zero. Finally, the list-size capacity requires that the number of messages that cannot be ruled out by the decoder have a rho-th moment that tends to one with the blocklength. Of the above, only the Shannon capacity has an explicit capacity, especially in the presence of a helper.

Relevant Common Information

In joint work with Michèle Wigger, our group is proposing a definition of "relevant common information" and studying some of its applications. We show that it has operational meanings that are analogous to those of Wyner's common Information in appropriately defined distributed problems of compression, simulation, and channel synthesis. Additionally, on a multiple-access channel with private and common messages, it is the minimal common-message rate that enables communication at the maximum sum-rate under a weak coordination constraint on the inputs and output. En route, the weak-coordination problem over a Gray-Wyner network is solved under the no-excess-rate constraint.

Guessing with Compressed Side Information

A source sequence is to be guessed with some fidelity based on a rate-limited description of an observed sequence with which it is correlated. The tension between the description rate and the exponential growth rate of the power mean of the required number of guesses in quantified. This can be viewed as the guessing version of the classical indirect-rate-distortion problem of Dobrushin-Tsybakov'62 and Witsenhausen'80. Judicious choices of the correlated sequence, the description rate, and the fidelity criterion recover a number of recent and classical results on guessing. In the context of security, our

work provides conservative estimates on a password's remining security after a number of bits from a correlated database have been leaked. (Joint work with Neri Merhav.)

Rate-Distortion Theory for Poisson Processes

In view of their importance in modeling biological systems, our group has had an enduring interest in lossy compression of point processes in general, and Poisson processes in particular. Recently, we have been studying this problem using a group theoretic approach. By describing a realization of a Poisson point process with either point timings or inter-point intervals and by choosing appropriate distortion measures, we formulated rate-distortion problems for realizations of the hyperoctahedral group in R^n. Specifically, the realizations we investigate are a hypercube and a hyperoctahedron. Thereby we unify three known rate-distortion problems of a Poisson process (with different distortion measures, but resulting in the same rate-distortion function) with the Laplacian-l1 rate-distortion problem.

3.3 Current Research Topics with Prof. Loeliger

Factor Graphs and State-Space Methods

We continue to find factor graphs to be very helpful in much of our research work, and we continue to develop the approach. In particular, much of our work in signal processing is based on linear state models and their factor graph representations.

Recursive Local Model Fitting

In an extension of state space methods, we continue to explore local model fitting by variations of recursive least squares, with a focus on polynomial models and multi-segment windows.

NUV Priors

Normal priors with unknown variance (NUV) allow to reduce many useful distributions and cost functions (including sparsifying priors) to Gaussians.
Recent results include NUV priors for half-plane constraints and for binarizing constraints.
We continue to explore the use of NUV priors, especially for linear state space models, where the actual computations boil down to multivariate Gaussian message passing (i.e., variations of Kalman smoothing).

Imaging

We continue to explore the use of NUV priors (see above) for imaging (in collaboration with Prof. Konukoglu).

Model-based Deep Learning

We explore the combination of explicit models (i.e., state space models) with data-based deep learning.

"Neural" Computation and Memorization

We continue to explore memorization and learning by networks of spiking neurons.

Analog-to-Digital Conversion

We continue to develop and to explore control-bounded analog-to-digital conversion.

3.4 Publications

A. Lapidoth, Y. Yan	"The Listsize Capacity of the Gaussian Channel with Decoder Assistance", Entropy, vol. 24, no. 1, January 2022, art. no.29
B. Ma, N. Zalmai, H.-A. Loeliger	"Smoothed-NUV Priors for Imaging", IEEE Trans. on Image Processing, 2022, vol. 31, pp. 4663-4678
G. Revach, N. Shlezinger, T. Locher, X. Ni, R.J.G. van Sloun, Y.C. Eldar	"Unsupervised Learned Kalman Filtering", 2022 European Signal Processing conference (EUSIPCO)
X. Ni, G. Revach, N. Shlezinger, R.J.G. van Sloun, Y.C. Eldar	"RTSNet: Deep Learning Aided Kalman Smoothing", 2022 Int. Conf. on Acoustic, Speech and Signal Processing (ICASSP)
J.P. Merkofer, G. Revach, N. Shlezinger, R.J.G. van Sloun	"Deep Augmented MUSIC Algorithm for Data-Driven DoA Estimation", 2022 IEEE Int. Conf. on Acoustics, Speech and Signal Processing (ICASSP)
I. Klein, G. Revach, N. Shlezinger J.E. Mehr, R.J.G. van Sloun, Y.C. Eldar	"Uncertainty in Data-Driven Kalman Filtering for Partially Known State-Space Models", 2022 IEEE Int. Conf. on Acoustics, Speech and Signal Processing (ICASSP)
H.-A. Shen, S.M. Moser, J.-P. Pfister	"The Geometry of Uncoded Transmission for Symmetric Continuous Log-Concave Distributions", in Proc. 2022 Int. Zurich Seminar on Information and Communication (IZS'22), Zurich, Switzerland, Mar. 2 – 4, 2022, pp. 29 – 33
A. Lapidoth, P. Narayan	"New Mathematical Techniques in Information Theory", Workshop-Report No. 14/2022, Mathematisches Forschungs-institut Oberwolfach, Mar. 13 – 19, 2022
B. Wolff, T. Gafni, G. Revach, N. Shlezinger, K. Cohen	"Composite Anomaly Detection via Hierarchical Dynamic Search", 2022 IEEE Int. Symp. on Information Theory (ISIT)
G. Revach, N. Shlezinger, X. Ni, A. López Escoriza, R. van Sloun, Y.C. Eldar	"KalmanNet: Neural Network Aided Kalman Filtering for Partially Known Dynamics", 2022 IEEE Transactions on Signal Processing, vol. 70, 1532-1547
F. Feyling, H. Malmberg, C. Wulff H.-A. Loeliger, T. Ytterdal	"High-level Comparison of Control-Bounded A/D Converters and Continuous-Time Sigma-Delta Modulators", 2022 IEEE Nordic Circuits and Systems Conf. (NorCAS), Oct. 25-26, 2022, Oslo, Norway
S. Ma, S.M. Moser, L. Wang, M. Wigger	"Signaling for MISO Channels under First- and Second-Moment Constraints", in Proc. 2022 IEEE Int. Symp. on Information Theory (ISIT'22), Helsinki, Finland, Jun. 25 – Jul. 1, 2022, pp. 2648-2653
F. Waldmann, C. Baeriswyl, R. Andonie, R. Wildhaber	"Onset Detection of Pulse-Shaped Bioelectrical Signals Using Linear State Space Models", Current Directions in Biomedical Engineering, vol. 8, no. 2, 2022, pp. 101-104

R. Graczyk, A. Lapidoth, N. Merhav, C. Pfister	"Guessing Based on Compressed Side Information", IEEE Transactions on Information Theory, vol. 68, no. 7, pp. 4244-4256, July 2022
R. Graczyk, A. Lapidoth, M. Wigger	"Conditional and Relevant Common Information", Information and Inference: A Journal of the IMA, 2022
S.M. Moser	"Advanced Topics in Information Theory (Lecture Notes)", 5th edition, Signal and Information Processing Lab, ETH Zürich, Switzerland, and Institute of Communications Engineering, National Yang Ming Chiao Tung University (NYCU), Hsinchu, Taiwan, 2022

3.5 Completed PhD Theses

Murer Patrick, *A New Perspective on Memorization in Recurrent Networks of Spiking Neurons,* ETH Diss. 28166 (Prof. Loeliger), Co-examiner: Prof. Wulfram Gerstner

Keusch Raphael, *Composite NUV Priors and Applications,* ETH Diss. 28471 (Prof. Loeliger). Co-examiner: Prof. Philipp Rostalski

4 Trips and Talks

4.1 Participation in Conferences and Meetings

G. Revach	IEEE Int. Conf. on Acoustics, (ICASSP), Speech and Signal Processing, Singapore, May 22-27, 2022
H.-A. Loeliger	Information Theory and Applications Workshop (ITA), San Diego, USA, May 22-27, 2022
E. Malmberg	IEEE Nordic Circuits and Systems Conf. (NorCAS), Oslo Norway, October 25-26, 2022
S.M. Moser	Information Theory Seminar at Cambridge University, UK, November 2022
A. Lapidoth, H.-A. Loeliger, S.M. Moser	Zurich Shannon Society Retreat, Spiez, July 7-8, 2022

4.2 Additional Lectures/Talks

S.M. Moser	"Energy-Optimal Signaling using the Example of Optical Communication", Information Theory Seminar at Cambridge University, UK, November 2022

4.3 Local Lectures and Seminars by Invited Speakers

February 7, 2022	Martin Haenggi *Wireless Networks and the Utopia of Peak Performance*
February 8, 2022	Rik Vullings *Signal Analysis for Unobtrusive Health Monitoring*
March 8, 2022	Ruud van Sloun *Imaging by imagination: Medical image acquisition and reconstruction by deep generative perception*
September 9, 2022	Tobias Koch *Second-Order Asymptotics of Haeffding-like Hypothesis Tests*
October 6, 2022	Deepanshu Vasal *Sequential linear coding for muti user Gaussian channels with active noisy feedback*

October 19, 2022	Ashok Vrdhan Makkuva *KO codes: Inventing Non-linear Encoding and Decoding for Reliable Wireless Communication via Deep-learning*
November 17, 2022	Michèle Wigger *Strong and epsilon-Dependent Converses for Source coding, Channel Coding, and Hypothesis Testing*

5 Service Activities

5.1 Conference Organization

Amos Lapidoth	Co-chair, Int. Zurich Seminar on Information and Communication (IZS) 2022
Stefan Moser	Co-chair, Int. Zurich Seminar on Information and Communication (IZS) 2022
	TPC Co-chair, 2023 IEEE International Symposium on Information Theory, Taipei, Taiwan

5.2 Other Service Activities

Amos Lapidoth	President, Zurich Shannon Society
Hans-Andrea Loeliger	President, ZuSem Foundation
Stefan Moser	Secretary, IEEE Switzerland Chapter on Digital Communication Systems
	Guest editor of Entropy: Special Issue on Information Theory for Communication Systems
	Secretary, Zurich Shannon Society