Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Signal and Information Processing Laboratory (ISI)

Annual Report 2023

Signal and Information Processing Laboratory
ETH Zurich, Sternwartstr. 7, CH-8092 Zurich
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Foreword

by Andi Loeliger

Again, we enjoyed the privilege of learning, doing research, teaching, and working with students. The pertinent records in this report may seem dry, but this is what we are passionate about.

Two of our PhD students, Raphael Keusch and Elizabeth Ren, finished their thesis and left us, with our best wishes. On the other side of the balance sheet, our alumnus Ligong Wang returned to us as a part-time senior scientist, and one new PhD student, Alessio Lukaj, joined us in November; welcome! More transitorily, Shraga Bross visited us in October–November.

Our usual skiing and hiking days – perfectly organized by Paddy Strebel – led us to Klosters/Davos and to the Walensee, respectively.

Contents

1 People

Professors:	Amos Lapidoth Hans-Andrea Loeliger
Senior Scientist:	Stefan Moser Ligong Wang
Postdocs:	Hampus Malmberg Ran Tamir Reto Wildhaber
Research Assistants / PhD Students:	Hugo Aguettaz Raphael Keusch Yunpeng Li Alessio Lukaj 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)
- *Information Theory II*, Prof. Lapidoth and S. Moser (Master)
- *Introduction to Estimation and Machine Learning*, Prof. Loeliger (Bachelor & Master)
- *Model-Based Estimation and Signal Analysis*, Prof. Loeliger (Master)
- *Algebra and Error Correcting Codes*, Prof. Loeliger (Master)
- Communication Systems, S. Moser and Prof. C. Studer (Bachelor)

Courses by External Lecturers

- *Acoustics I*, Reto Pieren (Master)
- *Acoustics II*, Reto Pieren (Master)
- *Analog Signal Processing and Filtering*, Hanspeter Schmid (Master)

2.2 Lab Courses

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

2.3 Student Projects

Student(s)	Title	Supervisor(s)
Semester Projects, Spring Term 2023		
Philipp Dasen	*Local Model Fitting for Radar Applications*	Hampus Malmberg
Victor Kawasaki-Borruat	*Capacity Bounds for MISO Channels Under 1st- and 2nd-Moment Constraints*	Stefan M. Moser Ligong Wang Amos Lapidoth
Arvid Berg, Simon Schläpfer	*ViT-nessing Mode connectivity after Permutations*	Sotirios Anagnostidis Sidak Pal Singh Thomas Hofmann (Hans-Andrea Loeliger)
Yinjia Liu	*RF localization*	Guy Revach
Luca Iten	*Mean Estimation in High-Dimensional Markov Gaussian Mixture Models with Rare Transistions*	Ran Tamir
Semester Projects, Fall Term 2023		
Torben Kölle	*HDL Implementation of an Adaptive Filter for Control-Bounded A/D Converters*	Hampus Malmberg
Carl Mikael Nordengren	*Quadrature Control Bounded Analog to Digital Converters*	Hampus Malmberg
Suvin Blum	*A Novel Approach to Building Binary Priors*	Alessio Lukaj Hugo Aguettaz
Ziyi Wang	*DoA Estimation with New Frequency Estimation Algorithm*	Hampus Malmberg
Bachelor Projects, Fall Term 2023		
Sophie Legler	*Solving Puzzles by Iterative Constraint Propagation*	Hugo Aguettaz
Master Projects, Spring Term 2023		
Mengyuan Zhao	*NUV-based Direction of Arrival (DoA) Estimation*	Guy Revach

Xiaoyong Ni	*Multi-Context State Estimation*	Guy Revach
Stefan Schucker	*Spatia Audio Rendering of Underwater Sound – using Ambisonics*	Jörg Rychen (Hans-Andrea Loeliger)
Jiayi Wu	*Beam Tracking in mmWave Communication Scenario*	Guy Revach
Thomas Dubach	*Towards Optimal Circuit Knitting*	David Sutter Christophe Piveteau Victor Gitton (Hans-Andrea Loeliger)
Hugo Umbers	*Offset Detection in GNSS Time Series Data*	Hans-Andrea Loeliger B. Soja Roland Hohensinn Elizabeth Ren
Alessio Lukaj	*A New Approach to Decoding Reed Muller Codes with Composite NUV Priors*	Hans-Andrea Loeliger Hugo Aguettaz Yunpeng Li
Arsim Dzambazoski	*Detecting Decaying Sinusoids for NMR Spectra*	Hans-Andrea Loeliger Hampus Malmberg Elizabeth Ren Hugo Aguettaz Nicolas Schmid
Andreas Kreuzmann	*Automated Audio Mixing*	Elizabeth Ren Hampus Malmberg Michael Leber

Master Projects, Fall Term 2023

Itamar Aharoni	*Low Rate Feedback Communication*	Amos Lapidoth Ligong Wang Helmut Bölcskei
Luca Iten	*On Composite NUV Priors and Hierarchical Models*	Hans-Andrea Loeliger Hugo Aguettaz Alessio Lukaj

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
- NUP 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 is 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 remaining 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 multi-segment polynomial models.

NUP Priors

Normal priors with unknown parameters (NUP) allow to reduce many useful distributions and cost functions (including sparsifying priors) to Gaussians. Recent results include NUP priors for half-plane constraints and for binarizing constraints. We continue to explore the use of NUP 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 NUP 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, B. Ni	"The Identification Capacity of the Modulo-Additive Noise Channel with Help", in Proceedings 2023 IEEE Int. Symp. on Information Theory (ISIT), Taipei, Taiwan, Jun. 25-30, 2023, pp. 13-14
A. Lapidoth, B. Ni	"Assisted Identification over Modulo-Additive Noise Channels", Entropy, vol. 25, no. 9, Sep. 2023, art. no. 1314
A. Lapidoth, Y. Yan	"On the Zero-Error Capacity with Helper", in Proceedings 2023 IEEE Int. Symp. on Information Theory (ISIT), Taipei, Taiwan, Jun. 25-30, 2023, pp. 1208-1212
H.-A. Loeliger	"On NUP Priors and Gaussian Message Passing", IEEE Int. Workshop on Machine Learning for Signal Processing (MLSP), Sept. 2023
H. Deng, G. Revach, H. Morgenstern, N. Shlezinger	"KalmanBOT: KalmanNET-Aided Bollinger Bands for Pairs Trading", IEEE Int. Conf. on Acoustics, Speech and Signal Processing (ICASSP), Jun. 2023
D.H. Shmuel, J.P. Merkofer, G. Revach, R.J.G. van Sloun, N. Shlezinger	"Deep Root MUSIC Algorithm for Data-Driven DoA Estimation", IEEE Int. Conf. on Acoustics, Speech and Signal Processing (ICASSP), Jun. 2023
T. Locher, G. Revach, N. Shlezinger R.J.G. van Sloun, R. Vulings	"Hierarchical Filtering with Online Learned Priors for ECG Denoising", IEEE Int. Conf. on Acoustics, Speech and Signal Processing (ICASSP), Jun. 2023
S. Truzman, G. Revach, N. Shlezinger, I. Klein	"Outlier-Insensitive Kalman Filtering Using NUV Priors", IEEE Int. Conf. on Acoustics, Speech and Signal Processing (ICASSP), Jun. 2023
I. Buchnik, D. Steger, G. Revach, R.J.G. van Sloun, T.S. Routtenberg, N. Shlezinger	"Learned Kalman Filtering in Latent Space with High-Dimensional Data", IEEE Int. Conf. on Acoustics, Speech and Signal Processing (ICASSP), Jun. 2023
S. Goldgraber Casspi, O. Hüsser, G. Revach, N. Shlezinger	"LQGNET: Hybrid Model-Based and Data-Driven Linear Quadratic Stochastic Control", IEEE Int. Conf. on Acoustics, Speech and Signal Processing (ICASSP), Jun. 2023
G. Revach, X. Ni, N. Shlezinger, R.J.G. van Sloun, Y.C. Eldar	"RTSNet: Learning to Smooth in Partially Known State-Space Models", IEEE Transactions on Signal Processing, vol. 71, pp 4441-4456, 2023
T. Gafni, B. Wolff, G. Revach, N. Shlezinger, K. Cohen	"Anomaly Search over Discrete Composite Hypotheses in Hierarchical Statistical Models", IEEE Trans. Signal Processing, vol. 71, pp. 202-217, 2023, doi: 10.1109/TSP.2023.3242074
H. Malmberg, F. Feyling, J. de la Rosa	"Quadrature Control-Bounded ADCs", IEEE Int. Midwest Symp. on Circuits and Systems (MWSCAS), Aug. 2023

F. Feyling, H. Malmberg, C. Wulff H.-A. Loeliger, T. Ytterdal	"Design and Analysis of the Leapfrog Control-Bounded A/D Converter", IEEE Trans. on Very Large Scale Integration (VLSI) Systems, 2023
J.-H. Yu, H.-A. Loeliger	"The Partial-Inverse Approach to Linearized Polynomials and Gabidulin Codes with Applications to Network Coding", IEEE Trans. Information Theory, Jun. 2023, doi: 10.1109/TIT.2023.3236720
H.-A. Shen, S.M. Moser, J.-P. Pfister	"A Generalization of the Equal Coding Theorem", in Proceedings, IEEE Information Theory Workshop (ITW'23), Saint-Malo, France, Apr. 23-28, 2023, pp. 329-334
R. Tamir	"Entropy Rate Bounds of Integer-Valued Processes via Second-Order Statistics", IEEE Transactions on Information Theory, vol. 69, no. 4, pp. 2120-2134, Apr. 2023, doi: 10.1109/TIT.2022.3224563
R. Tamir	"Entropy Rate Bounds of Integer-Valued Processes via Second-Order Statistics" in Proceedings 2023 IEEE Information Theory Workshop (ITW 2023), Saint-Malo, France, Apr. 2023, doi: 10.1109/ITW55543.2023.10160242
R. Tamir	"On Correlation Detection of Gaussian Databases via Local Decision Making" in Proceedings 2023 IEEE International Symposium on Information Theory (ISIT 2023), Taipei, Taiwan, Jun. 2023, pp. 1231-1236, doi: 10.1109/ISIT54713.2023.10206834
R. Tamir	"Reaching Consensus in Dense Erdös-Rényi Graphs" in Proceedings IEEE International Symposium on Information Theory (ISIT 2023), Taipei, Taiwan, Jun. 2023, pp. 1669-1674, doi: 10.1109/ISIT54713.2023.10206754
R. Tamir, N. Merhav	"Error Exponents of the Dirty-Paper and Gel'fand-Pinsker Channels" IEEE Transactions on Information Theory, vol. 69, no. 12, pp. 7479-7498, Dec. 2023, doi: 10.1109/TIT.2023.3314210
R. Tamir, N. Merhav	"Error Exponents of the Dirty-Paper and Gel'fand-Pinsker Channels" in Proceedings 2023 IEEE Information Theory Workshop (ITW 2023), Saint-Malo, France, Apr. 2023, doi: 10.1109/ITW55543.2023.10161668

3.5 Completed PhD Theses

Ren Elizabeth, *Using Local State Space Model Approximation for Fundamental Signal Analysis Tasks,* ETH Diss. 28986 (Prof. Loeliger), Co-examiner: Prof. Ivan Selesnick

4 Trips and Talks

4.1 Participation in Conferences and Meetings

A. Lapidoth, S.M. Moser, L. Wang	IEEE Information Theory and Tapas Workshop (ITTW), Madrid, Spain, Jan. 24-27, 2023
A. Lapidoth	Cambridge Information Theory Colloquium 2023, Cambridge, UK, Apr. 21, 2023
Ran Tamir	IEEE Information Theory Workshop, Saint-Malo, France, Apr. 23-28, 2023
G. Revach	IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), Rhodes Island, Greece, Jun. 4-10, 2023
A. Lapidoth, H.-A. Loeliger, S.M. Moser, L. Wang, R. Tamir, Y. Yan, B. Ni (online-participation)	IEEE International Symposium on Information Theory (ISIT), Taipei, Taiwan, Jun. 25-30, 2023
Y. Yan, B. Ni	IEEE European-School of Information Theory 2023, Bristol, UK, Jul. 17-21, 2023
A. Lapidoth, H.-A. Loeliger, S.M. Moser	ZSS Zurich Shannon Society Retreat, Konolfingen, Switzerland, Jul. 24-25, 2023
H. Malmberg	IEEE International Midwest Symposium on Circuits and Systems (MWSCAS), Phoenix, USA, Aug. 6-9, 2023
H.-A. Loeliger	Signal Processing and Friends Workshop (LCAV25), EPFL Lausanne, Aug. 24-25, 2023
H.-A. Loeliger	International Symposium on Topics in Coding (ISTC), Brest, France, Sep. 4-8, 2023
H.-A. Loeliger	IEEE International Workshop on Machine Learning for Signal Processing (MLSP), Rome, Italy, Sep. 17-20, 2023

4.2 Additional Lectures/Talks

S.M. Moser	"Energy-optimal signaling using the example of optical communication", Information Theory and Tapas Workshop (ITTW), Madrid, Spain, Jan. 26, 2023
L. Wang	"State-Dependent DMC with a Causal Helper", Information Theory and Tapas Workshop (ITTW) Madrid, Spain, Jan. 27, 2023
S.M. Moser	"Energy-optimal-signaling using the example of optical communication", University of Bern, Department of Physiology, Bern, Switzerland, Mar. 20, 2023
A. Lapidoth	"A little help goes a long way", Cambridge Information Theory Colloquium (CITC), Cambridge, UK, Apr. 21, 2023

4.3 Local Lectures and Seminars by Invited Speakers

February 7, 2023	Shlomo Shamai *The Information Bottleneck: A Unified Information Theoretic View*
March 30, 2023	Anatoly Khina *The Information Velocity of Packet-Erasure Links*
April 18, 2023	Ran Tamir *On Entropy-Rate Bounds and Two Problems in Gaussian Database Models*
May 2, 2023	Cheuk Ting Li *Undecidability in Information Theory*
December 19, 2023	Ligong Wang *Distributed Hypothesis Testing*

5 Service Activities

5.1 Conference Organization

Amos Lapidoth	Co-chair, Int. Zurich Seminar on Information and Communication (IZS) 2024
Stefan Moser	Co-chair, Int. Zurich Seminar on Information and Communication (IZS) 2024
	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
	Secretary, Zurich Shannon Society