Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Signal and Information Processing Laboratory (ISI)

Annual Report 2021

Signal and Information Processing Laboratory
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Foreword

by Hans-Andrea Loeliger

In the second year of the Covid pandemic, the pertinent restrictions and modi operandi had almost become routine. Nonetheless, we were much relieved when the virus seemed to take a break in the summer. In particular, we could do our usual summer hike, which led us via Brunnen and Seelisberg to the Rütli.

In fall 2020 and spring 2021, my previous regular course SML was split into two new regular courses (IEML and ASML), which further increased the heavy course-related load on our PhD students. Many thanks to all of them!

In fall 2021, Boxiao Ma and Robert Graczyk successfully defended their PhD thesis, which, sadly, implies that they will eventually leave us. On the bright side, Hugo Aguettaz joined us as a new PhD student.

Research has been as exciting as ever. Have a look at the papers and preprints...

Contents

1 People

Professors:	Amos Lapidoth Hans-Andrea Loeliger
Senior Researcher:	Stefan Moser
Postdocs:	Hampus Malmberg Ran Tamir Reto Wildhaber
Research Assistants / PhD Students:	Hugo Aguettaz Robert Graczyk Raphael Keusch Boxiao Ma Gian Marti Patrick Murer Elizabeth Ren Guy Revach 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 (6th Sem. Bachelor)
- *Information Theory II*, Prof. Lapidoth (Master)
- *Introduction to Estimation and Machine Learning*, Prof. Loeliger (Bachelor & Master)
- New: *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, Patrick Murer
- *Blackfin DSP,* Boxiao Ma
- *Electronic Circuits and Signals Exploration Laboratory,* Hampus Malmberg & Raphael Keusch

2.3 Student Projects

Student(s)	Title	Supervisor(s)
Semester Projects, Spring Term 2021		
Julian Merkofer	*Evaluation and Augmentation of the MUSIC Algorithm for Localization*	Guy Revach
Zixiao Li	*Deep Unfolding of BiNUV-EM for MIMO Detection*	Gian Marti Oscar Castañeda H.-A. Loeliger
Gaspard Fragnière	*Adaptive Sampling Strategies for solving A Hide & Seek game*	Guy Revach
Timur Locher	*Steady State Kalman Filtering and Domain Adaptation for KalmanNet*	Guy Revach
Xiaoyong Ni	*KalmanNet – Data Driven Kalman Filtering and Smoothing*	Guy Revach
Adrià López Escoriza	*KalmanNet for Autonomous Racing*	Guy Revach
Carla Tettamanti	*Multi-Input and Control Extensions to Control-Bounded A/D Conversion*	Hampus Malmberg
Jonas Roth	*Prototyping a Control-Bounded Hadamard Converter*	Hampus Malmberg
Nico Ruckstuhl	*Tracking and Locating Orca Calls*	Elizabeth Ren Gian Marti
Jonas Mehr	*Reducing the Complexity of KalmanNet*	Hans-Andrea Loeliger Guy Revach
Jerome Maurice Jeannin	*Evaluating the Sparse Recovery Problem using blind (NUV-based) and supervised (NN-based) approaches*	Guy Revach
Semester Projects, Fall Term 2021		
Victor Hertz	*Likelihood Profiles and List Decoding of Polar codes*	Hans-Andrea Loeliger Raphael Keusch
Marko Tosic	*Sensitivity to Model Uncertainty in Model-Based Kalman Filters*	Guy Revach
Felix Rüssli	*GAN-Based Image Steganography*	Guy Revach

Sidharth Ramesh	*Model Based Localization*	Guy Revach
Xi Chen	*Kalman Filtering in High Dimensions with Visual Observations*	Hans-Andrea Loeliger Guy Revach

Master Projects, Spring Term 2021

Aurel Schmid	*Automatic Image Annotation of Historical* Photographs	Boxiao Ma Hans-Andrea Loeliger

Master Projects, Fall Term 2021

Julian Merkofer	*Evaluations and Improvements of the Augmented MUSICC Algorithm*	Guy Revach

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

Factor graphs are a graphical notation for system models and algorithms in a large variety of fields including error correcting codes, signal processing, statistical physics, linear algebra, and more. We find factor graphs to be very helpful in most 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 space models, which are naturally expressed as factor graphs.

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. 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).

Recent results include the discovery of NUV priors for binary constraints and for half-plane constraints.

Imaging and Tomography

We continue to explore the use of NUV priors (see above) for imaging in general and tomography in particular.

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 have long been working on analog-to-digital conversion, and significant progress was made also this year.

3.4 Publications

A. Lapidoth and G. Marti	"Encoder-Assistance for Additive Noise Channels", in Proceedings 2020 IEEE Information Theory Workshop (ITW'20), pp. 1–5, April 2021
A. Lapidoth, G. Marti and Y. Yan	"Other helper capacities", in Proceedings 2021 IEEE International Symposium on Information Theory (ISIT'21), pp. 1272-1277, July 2021
E. Ren, G. Cid Ornelas and H.-A. Loeliger	"Real-time interaural time delay estimation via onset detection", 2021 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), June 6-11
G. Marti, B. Ma and H.-A. Loeliger	"Why maximum-a-posteriori blind image deblurring works after all", 29th European Signal Processing conference (EUSIPCO), August 2021
G. Marti, R. Keusch and H.-A. Loeliger	"Multiuser MIMO detection with composite NUV priors", Int. Symposium on Topics in Coding 2021 (ISTC), August/ September 2021
G. Revach, N. Shlezinger, R.J.G. van Sloun and Y.C. Eldar	"KalmanNet: data-driven Kalman filtering", 2021 IEEE Int. Conf. of Acoustics, Speech and Signal Processing (ICASSP), June 2021
A. López Escoriza, G. Revach, N. Shlezinger and R.J.B. van Sloun	"Data-driven Kalman-based velocity estimation for autonomous racing", 2021 IEEE International Conference on Autonomous Systems (ICAS)
H. Malmberg, G. Wilckens and H.-A. Loeliger	"Control-bounded analog-to-digital conversion" Circuits, Systems, and Signal Processing, 2021
R. Keusch, H. Malmberg and H.-A. Loeliger	"Binary control and digital-to-analog conversion using composite NUV priors and iterative Gaussian message passing", 2021 IEEE Int. Conf. on Acoustics, Speech and Signal Processing (ICASSP), June 2021
R. Tamir and N. Merhav	"Universal Decoding for the Typical Random Code and for the Expurgated Code", IEEE Transactions on Information Theory, 2021
R. Graczyk, A. Lapidoth and M. Wigger	"Conditional and Relevant Common Information" to appear in Information and Inference: A Journal of the IMA, 2021
R. Graczyk, A. Lapidoth and Y. Yan	"Guessing a Tuple", in Proceedings 2021 IEEE International Symposium on Information Theory (ISIT'21), pp. 1997-2001, Juli 2021
R. Graczyk and I. Sason	"On Two-Stage Guessing", Information, vol. 12, no. 4, art. no. 159, April 2021
H.-A. Shen, S. Moser and J.-P. Pfister	"Sphere Covering for Poisson Processes", in Proceedings 2020 IEEE Information Theory Workshop (ITW'20), pp. 181-185, April 2021

H.-A. Shen, S. Moser and J.-P. Pfister	"Rate-Distortion Problems of the Poisson Process: a Group-Theoretic Approach", in Proceedings 2021 IEEE Information Theory Workshop (ITW'21), pp. 1-6, Oktober 2021
R. Keusch and H.-A. Loeliger	"A binarizing NUV prior and its use for M-level control and digital-to-analog conversion", arXiv:2105.02599
R. Keusch and H.-A. Loeliger	"Half-space and box constraints as NUV priors: first results", arXiv:2109.00036

3.5 Completed PhD Theses

Boxiao Ma, *Smoothed-NUV Priors for Imaging and Beyond,* ETH Diss. 27927 (Prof. Loeliger), Co-examiner: Prof. Ender Konukoglu

Robert Graczyk, *Guess What?*, ETH Diss. 28092 (Prof. Lapidoth). Co-examiners: Prof. Igal Sason, Prof. Emre Telatar

4 Trips and Talks

4.1 Participation in Conferences and Meetings

Many ISI members participated at various conferences (cf. Section 3.4). However, all conferences this year were by video conference only and thus involved not trips.

4.2 Additional Lectures/Talks

"NUV Representations and Applications, Old and New", plenary talk at Int. Symposium on topics in Coding 2021 (ISTC), August/Sept. 2021, Zoom

4.3 Local Lectures and Seminars by Invited Speakers

January 12, 2021	Loai Danial *Neuromorphic Data Converters using Memristors*
February 2, 2021	Deddy Lavid *AI Entrepreneurship*
February 16, 2021	Tomer Goshen *Multichannel Acoustic Signal Processing and Beamforming in Practical applications, and the Use of DNN in that Area*
November 25, 2021	Amin Shokrollahi *Chord Signaling and Internship Opportunities at Kandou*

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

5.2 Other Service Activities

Amos Lapidoth	Executive Board Member, IEEE Transactions on Information Theory
	Guest editor of Entropy: Special Issue on Information Measures
	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