Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Signal and Information Processing Laboratory (ISI)

Annual Report 2020

Signal and Information Processing Laboratory
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Foreword

by Amos Lapidoth

What a year 2020 has been! It began, like every other even-numbered year, with a successful International Zurich Seminar (IZS), which our institute organizes biennially. None of us knew at the time that this would be the last "live" conference we would attend for quite some time. But shortly after the conference, Covid-19 forced a lockdown on us, and the abnormal part of the year began.

Just before the lockdown, we still managed to bid Ms. Silvia Tempel farewell in person and to wish her the very best for her retirement. But her replacement, Ms. Olivia Popov-Bärtsch would only join us during the lockdown. She literally spent her first few months working from home. And it was only via Zoom that we learned how lucky we were to have her in our institute.

The lockdown presented enormous challenges for our teaching, student supervision, lab-work, and research. Looking back, I am exceedingly proud of how well our institute rose to the challenge. All showed incredible motivation and creativity in making this work. Paddy, for example, demonstrated superb workmanship in setting up the plastic partitions that enabled oral exams and shared offices. It is truly remarkable how seamless the transition to on-line teaching and on-line supervision has been.

Ph.D. graduations continued nearly normally, with the live defense replaced by a virtual one. Fortunately, the degrees conferred on our fresh graduates - Ruksana Giuarda and Hampus Malmberg - come with the same “all the rights and privileges pertaining thereto” clause that a live defense confers. Congratulations to them both!

Finally, we welcome Yiming Yan who has taken her first steps towards a Ph.D. in 2020.

Writing these words in July 2021, I can only hope that the pandemic be completely eradicated, that the sick fully recover, and that things return to normal soon.

Amos Lapidoth

Contents

1 People

Professors:	Amos Lapidoth Hans-Andrea Loeliger
Senior Researcher:	Dr. Stefan Moser
Postdocs:	Hampus Malmberg Reto Wildhaber
Research Assistants / PhD Students:	Robert Graczyk Raphael Keusch Boxiao Ma Gian Marti Patrick Murer Elizabeth Ren Guy Revach Yiming Yan
Technical Staff:	Patrik Strebel
Secretaries:	Silvia Tempel 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)
- New: *Introduction to Estimation and Machine Learning*, Prof. Loeliger (Bachelor & Master)
- *Signal Analysis, Models, 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 (Master)
- *Analog Signal Processing and Filtering*, Dr. Hanspeter Schmid (Master)

2.2 Lab Courses

- Fachpraktika, Patrick Murer
- *Blackfin DSP,* Boxiao Ma & Gian Marti
- *Electronic Circuits and Signals Exploration Laboratory,* Hampus Malmberg & Raphael Keusch

2.3 Student Projects

Student(s)	Title	Supervisor(s)
Semester Projects, Spring Term 2020		
Yashas Annadani	*Dropin: Encouraging Factorisation in Deep Generative Models*	Stefan Bauer, (D-INFK, MPI) Bernhard Schölkopf (D-INFK, MPI) and H.-A. Loeliger
Sebastian Kurella	*High-Performance GPU Training of Decision Trees for Gradient Boosting Models*	H.-A. Loeliger
Semester Projects, Fall Term 2020		
Benjamin Wolff	*Automated Drumming Transcription*	Hampus Malmberg and Elizabeth Ren
Ke Zhang	*Local Frequency Estimation*	Elizabeth Ren
Ali Fahri Ander	*Clustering with Iteratively Reweighted Descent*	Elizabeth Ren
Adrià López Escoriza	*KalmanNet: Data-driven Kalman Filtering for Non-Linear System Models*	Guy Revach
Haoran Deng	*On the Nature of the Capacity-Achieving Input Distribution for the Additive Uniform Noise Channel*	Amos Lapidoth
Davide Materia	*The Computational Cut-Off Rate under Cost Constraint*	Amos Lapidoth
Master Projects, Spring Term 2020		
Gustavo Cid Ornelas	*Robust Time Delay Estimation via Onset Detection Filter Bank*	Elizabeth Ren
Gian-Marco Hutter	*Timbre Transfer on Singing Voices*	Guy Revach
Yiming Yan	*Helpers Increase the Error-Free Capacities with Erasures and Lists*	Amos Lapidoth

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

- Fundamentals and applications of factor graphs
- State-space methods
- Sparsity and unsupervised signal decomposition
- Imaging and tomography
- “Neural” computation and signal processing
- Analog-to-digital conversion

3.2 Current Research Topics with Prof. Lapidoth

Guessing with Distributed Encoders

Two correlated sources emit a pair of sequences, each of which is observed by a different encoder. Each encoder produces a rate-limited description of the sequence it observes, and the two descriptions are presented to a guessing device that repeatedly produces sequence pairs until correct. The number of guesses until correct is random, and it is required that it have a moment (of some prespecified order) that tends to one as the length of the sequences tends to infinity. The description rate pairs that allow this are characterized in terms of the Rényi entropy and the Arimoto-Rényi conditional entropy of the joint law of the sources. This solves the guessing analog of the Slepian-Wolf distributed source-coding problem.

Applications to the distributed storage of passwords are examined.

Multiplexing Zero-Error and Rare-Error Communications over a Noisy Channel

Two independent data streams are to be transmitted over a noisy discrete memoryless channel with noiseless (ideal) feedback. Errors are tolerated only in the second stream, provided that they occur with vanishing probability. The rate of the error-free stream cannot, of course, exceed the channel's zero-error feedback capacity, and nor can the sum of the streams' rates exceed the channel's Shannon capacity. Using a suitable coding scheme, these necessary conditions are shown to characterize all the achievable rate pairs. Planning for the worst channel behavior - as is needed to achieve zero-error communication - and planning for the typical channel behavior - as is needed to communicate near the Shannon limit - are thus not incompatible.

It is further shown that feedback may be beneficial for the multiplexing problem even on channels on which it does not increase the zero-error capacity.

Broadcasting a Gaussian source and independent data streams

We study a scenario where a Gaussian source and two data streams are to be transmitted over a Gaussian broadcast channel: the first stream, the “common stream”, is to be decoded by both receivers, and the second, the “private stream”, only by the strong receiver. Both receivers wish to estimate the source sequence, though with possibly different mean squared-errors. We characterize the quadruples of achievable rates and estimation errors.

Semi-robust communications

We study the capacity region of a network with one transmitter and two receivers: an “ordinary receiver” and a “robust receiver”. The channel to the ordinary receiver is a given (known) discrete memoryless channel, whereas the channel to the robust receiver is an arbitrarily varying channel. Both receivers are required to decode the “common message” (the better-protected message), whereas only the ordinary receiver is required to decode the “private message” (the less-protected message).

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, a coding technique is proposed here 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.

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).

Most recently, we have discovered the use of NUV priors for binary and M-level signals.

Imaging and Tomography

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

“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

S. Bross, A. Lapidoth and G. Marti	"Decoder-Assisted Communications over Additive Noise Channels", IEEE Transactions on Communications, vol. 68, pp. 4150-4161, July 2020
C. Bleuler, A. Lapidoth and C. Pfister	"Conditional Rényi Divergences and Horse Betting", Entropy, vol. 22, pp. 316, March 2020
H.-A. Loeliger and P.O. Vontobel	"Quantum measurement as marginalization and nested quantum systems", IEEE Transactions on Information Theory, vol. 66, pp. 3485-3499, June 2020
P. Murer and H.-A. Loeliger	"Online memorization of random firing sequences by a recurrent neural network", IEEE International Symposium on Information Theory (ISIT), June 2020
R. Graczyk and A. Lapidoth	"Gray-Wyner And Slepian-Wolf Guessing", IEEE International Symposium on Information Theory (ISIT), pp. 2207-2211, June 2020
R. Graczyk and A. Lapidoth	"Gray-Wyner And Slepian-Wolf Guessing", IEEE International Symposium on Information Theory (ISIT), pp. 2189-2193, June 2020
L. Li, S. Moser, L. Wang and M. Wigger	"On the Capacity of MIMO Optical Wireless Channels", IEEE Transactions on Information Theory, vol. 66, no. 9, pp. 5660-5682, September 2020
S. Moser	"Expected Logarithm and Negative Integer Moments of a Noncentral χ^2-Distributed Random Variable", Entropy, vol. 22, art. no. 1048, September 2020
B. Ma, J. Trisovic and H.-A. Loeliger	"Multi-Image blind Deblurring Using a Smoothed NUV Prior and Iteratively Reweighted Coordinate Descent", 2020 IEEE International Conference on Image Processing (ICIP), October 2020
A. Lapidoth and G. Marti	"Encoder-Assisted Communications over Additive Noise Channels", IEEE Transactions on Information Theory, vol. 66, no. 11, pp. 6607-6616, November 2020, doi: 10.1109/TIT.2020.3012629
R.A. Wildhaber, E. Ren, F. Waldmann and H.-A. Loeliger	"Signal analysis using local polynominal approximations", 28th European Signal Processing conference (EUSIPCO 2020), Januar 2021
F. Wadehn, T. Weber, D. Mack, T. Heldt, H.-A. Loeliger	"Model-Based Separation, Detection, and Classification of Eye Movements", IEEE Transactions on Biomedical Engineering, vol. 67, pp. 588-600, February 2020
H.-A. Loeliger, H. Malmberg and G. Wilckens	"Control-bounded analog-to digital conversion: transfer function analysis, proof of concept, and digital filter implementation", arXiv:2001.05929

3.5 Completed PhD Theses

Hampus Malmberg, *Control-Bounded Converters*, ETH Diss. 27025 (Prof. Loeliger). Co-examiners: Prof. Boris Murmann, Prof. Hanspeter Schmid

Ruksana Giurda, *Improved Sound Classification by Means of Sound Localization in Hearing Devices,* ETH Diss. 27089 (Prof. Loeliger). Co-examiners: Prof. Norbert Dillier, Prof. Martin Kompis

4 Trips and Talks

4.1 Participation in Conferences and Meetings

H.-A. Loeliger	ITA 2020, Information Theory and Applications Workshops, San Diego, CA, USA, February 2-7, 2020
E. Malmberg	IEEE International Symposium of Circuits and Systems (ISCAS) 2020, Online May 17-20, 2020

4.2 Additional Lectures/Talks

H.-A. Loeliger	"Quantum probabilities, factor graphs, and measurement by marginalization", presented at (ITA 2020) Information Theory and Applications Workshop, San Diego, CA, USA, February 2-7, 2020

4.3 Local Lectures and Seminars by Invited Speakers

January 8, 2020	Branka Vucetic *Coding Schemes for Ultra-reliable Low-latency Communications (URLLC)*
January 17, 2020	Chandra Nair *Sub-additive functionals, information theory, and non-convex optimization*
February 17, 2020	Omer Sholev *Neural Network Coded MIMO Detection*

5 Service Activities

5.1 Conference Organization

Amos Lapidoth	Co-chair, Int. Zurich Seminar on Information and Communication (IZS) 2020
Stefan Moser	Co-chair, Int. Zurich Seminar on Information and Communication (IZS) 2020

5.2 Other Service Activities

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