Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

# Signal and Information Processing Laboratory (ISI)

# Annual Report 2019

Signal and Information Processing Laboratory
ETH Zurich, Sternwartstr. 7, CH-8092 Zurich
www.isi.ee.ethz.ch

# Foreword

by Hans-Andrea Loeliger

Research in 2019 has been as exciting as ever, with discoveries and insights to be detailed elsewhere.

Three of our PhD students got their PhD: Federico Wadehn, Reto Wildhaber, and Christoph Pfister. Unfortunately, that means they left us (except that Reto Wildhaber will be around part-time a little longer). On the other hand, we have been joined by two new PhD students: Guy Revach and Gian Marti.

And there have been more changes: Rita Hildebrand, our secretary for over ten years, retired in April and has been succeeded by Simone Ammann. Goodbye to those who left, and welcome to those who joined!

Another highlight was the reunion on June 24 of former ISI members, including George Moschytz and many of his former PhD students. Almost 70 participants enjoyed seeing old friends, three presentations, and a splendid dinner.

Yet another highlight was our traditional hiking day, which lead us to the Wildkirchli and the Schäfler in the Alpstein massif.

# Contents

# 1 People

| | |
|---|---|
| **Professors:** | Amos Lapidoth<br>Hans-Andrea Loeliger |
| **Senior Researcher:** | Dr. Stefan Moser |
| **Research Assistants / PhD Students:** | Robert Gracyk<br>Raphael Keusch<br>Boxiao Ma<br>Hampus Malmberg<br>Gian Marti<br>Patrick Murer<br>Christoph Pfister<br>Elizabeth Ren<br>Guy Revach<br>Federico Wadehn<br>Reto Wildhaber |
| **Technical Staff:** | Patrik Strebel |
| **Secretaries:** | Rita Hildebrand<br>Silvia Tempel<br>Simone Ammann |

# 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 Stefan Moser (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, Elizabeth Ren
- *Blackfin DSP,* Boxiao Ma
- *Electronic Circuits and Signals Exploration Laboratory,* Hampus Malmberg & Patrick Murer

## 2.3 Student Projects

| Student(s) | Title | Supervisor(s) |
|---|---|---|
| **Semester Projects, Spring Term 2019** | | |
| Vincent Wüst | *Multi-Channel Pattern Learning Using Feature Detection Filters* | Raphael Keusch<br>Patrick Murer |
| Nina Stumpf | *Iterative Message Passing for Phylogeographic Likelihood Computation* | Timothy Vaughan (D-BSSE),<br>Patrick Murer |
| Jelena Trisovic | *Blind Image Deblurring Using Multiple Measurements* | Boxiao Ma |
| Yiming Yan | *Guessing a Tuple* | Robert Graczyk |
| **Semester Projects, Fall Term 2019** | | |
| Gustavo Cid Ornelas | *Sound Source Localization via Onset Detection* | Elizabeth Ren, |
| Maxim Haas | *Multi-Layer Blind Sparse Signal Learning* | Elizabeth Ren |
| **Bachelor Group Project, Spring Term 2019** | | |
| Alessandro Tell,<br>Mohamed Ibrahim,<br>Tim Gretler | *Isolated Word Recognition using Deep Neural Networks* | Elizabeth Ren,<br>Raphael Keusch |
| **Master Projects, Spring Term 2019** | | |
| Gian Marti | *Channels with a Helper* | *A. Lapidoth* |
| **Master Projects, Fall Term 2019** | | |
| Nina Stumpf | *Model-based and Bandpass Filtering Approaches for Water Leak Detection* | H.-A. Loeliger,<br>Elizabeth Ren |

# 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.

### Mismatched Decoding in the Presence of Feedback

For a given channel and a given decoding rule, the mismatch capacity is the highest rate at which reliable communication is possible on the channel using the given decoding rule. How to compute the mismatch capacity is a long-standing open problem in Information Theory. Here we study this problem in the presence of a feedback link from the channel's output to the encoder. We show that – although feedback does not increase the Shannon capacity of memoryless channels – feedback can increase the mismatch capacity. In fact, in its presence, the mismatch capacity may equal the Shannon capacity even when the decoding rule differs significantly from the maximum-likelihood rule.

## 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. Preparations for a patent application are in progress.

### 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. A paper on memorization has been submitted to ISIT 2020.

### Analog-to-Digital Conversion

We have long been working on analog-to-digital conversion, and significant progress was made this year. Preparations for a patent application are in progress.

### Foundations of Quantum Mechanics

We continued joint work with Pascal Vontobel (Hongkong) on factor graph representations of probabilities and measurements in quantum mechanics.

## 3.4 Publications


| | |
|---|---|
| A. Bracher, E. Hof and A. Lapidoth | "Guessing Attacks on Distributed-Storage Systems", IEEE Transactions on Information Theory, vol. 65, no. 11, pp. 6975-6998, Nov. 2019 |
| A. Bracher, A. Lapidoth and C. Pfister, | "Guessing with distributed encoders", *Entropy,* vol. 21, no. 3, March 2019, pp. 298 |
| S. Bross and A. Lapidoth | "The Gaussian Source-and-Data-Streams Problem", IEEE Transactions on Communications, vol. 67, no.8, pp. 5618-5628, Aug. 2019 |
| A. Lapidoth and C. Pfister | "Two Measures of Dependence", *Entropy*, vol. 21, no. 8, Aug. 2019, pp. 778 |
| C. Bleuler, A. Lapidoth and C. Pfister | "Gambling and Rényi Divergence", Proc. 2019, IEEE International Symposium on Information Theory (ISIT), Paris, France, July 7-12, 2019, pp. 2214-2218 |
| E. Ren and H.A. Loeliger | "Exact discrete-time realizations of the gammatone filter", IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), Brighton, UK, May 12-17, 2019 |
| J.-P. Schulze, A. Mrowca, E. Ren, H.-A. Loeliger and K. Böttinger | "Context by proxy: identifying contextual anomalies using an output proxy", 25th ACM SIGKDD Conf. On Knowledge Discovery and Data Mining (KDD), Anchorage, Alaska, USA, Aug. 4-8, 2019 |

| | |
|---|---|
| F. Wadehn, T. Weber and H.-A. Loeliger | "State space models with dynamical and sparse variances, and inference by EM message passing," 27th European Signal Processing Conference (EUSIPCO, A Coruña, Spain, Sept. 2-6, 2019 |
| J.-H. Yu and H.-A. Loeliger | "Decoding Gabidulin codes via partial inverses of linearized Polynomials", IEEE International Symposium on Information Theory (ISIT), Paris, France, July 7-12, 2019 |
| L. Li, S. Moser, L. Wang and M. Wigger | "On the Capacity of Block Fading Optical Wireless Channels", IEEE Global Communications Conference (Globecom'19, Waikoloa, Hawaii, USA, Dec. 9-13, 2019 |
| R. Graczyk and A. Lapidoth | "Two-Stage Guessing", IEEE, International Symposium on Information Theory (ISIT), Paris, France, July 7-12, 2019, pp. 475-479 |
| S. Moser | "Advanced Topics in Information Theory (Lecture Notes)", 4th edition, 2019 |
| T. Keresztfalvi and A. Lapidoth | "Multiplexing Zero-Error and Rare-Error Communications over a Noisy Channel", IEEE Transactions on Information Theory, vol. 65, no. 5, pp. 2824-2837, May 2019 |
| T. Keresztfalvi and A. Lapidoth | "Semi-Robust Communications Over a Broadcast Channel", *IEEE Transactions on Information Theory,* vol. 65, no. 8, pp. 5043-5049, Aug. 2019 |

## 3.5 Completed PhD Theses

Federico Wadehn, *State Space Methods with Applications in Biomedical Signal Processing,* ETH Diss. 25926 (Prof. Loeliger). Co-examiners: Prof. Thomas Heldt, MIT, Cambridge, USA, and Prof. Justin Dauwels, Nanyang Technological University, Singapore

Reto Andreas Wildhaber, *Localized State Space and Polynomial Filters with Applications in Electrocardiography*, ETH Diss. 25929 (Prof. Loeliger). Co-examiner: Prof. Ali Sayed, EPFL, Lausanne

Christoph Pfister, *On Rényi Information Measures and Their Applications,* ETH Diss. 26355 (Prof. Lapidoth). Co-examiner: Prof. Igal Sason, Technion, Haifa, Israel

# 4 Trips and Talks

## 4.1 Participation in Conferences and Meetings

| | |
|---|---|
| H.-A. Loeliger | ITA 2019, Information Theory and Applications Workshops, San Diego, CA, USA, Febr. 10-15, 2019 |
| H.-A. Loeliger | IEEE International Symposium on Information Theory (ISIT), Paris, France, July 7-12, 2019 |
| H.-A. Loeliger | Workshop on Mathematical Data Science, Dürnstein, Austria, Oct. 13-15, 2019 |
| E. Malmberg | Workshop on Advances on Analog Circuit Design (AACD) 2019, Milan, Italy, April 1-3, 2019 |
| E. Ren | IEEE International Conference on Acoustics, Speech & Signal Processing (ICASSP) 2019 Convention, Brighton, England, May 12-17, 2019 |
| Amos Lapidoth | Tel Aviv, Israel, Febr. 12.-17,2019 |
| Amos Lapidoth | Skopje, North Macedonia, April 7-8, 2019 |
| Amos Lapidoth | LSIT London Symposium on Information Theory, London, May 29-June 2, 2019 |
| Amos Lapidoth | IEEE International Symposium on Information Theory (ISIT), Paris, France, July 7-13, 2019 |
| Amos Lapidoth | IEEE Information Theory Workshop (ITW), Visby, Sweden, Aug. 25-28, 2019 |
| Amos Lapidoth | Workshop on Mathematical Data Science, Dürnstein, Austria, Oct. 13-15, 2019 |
| Stefan Moser | ISIT Paris, July 7-13, 2019 |
| Christoph Pfister | ISIT Paris, July 7-13, 2019 |
| Robert Graczyk | ISIT Paris, July 7-13, 2019 |

## 4.2 Additional Lectures/Talks

| | |
|---|---|
| H.-A. Loeliger | "Factor graphs with NUV priors and iteratively reweighted descent for sparse least squares and more", presented at (ITA 2019) Information Theory and Applications Workshop, San Diego, CA, USA, Febr. 10-15, 2019 |
| | "On Least squares with NUV priors", Workshop on Mathematical Data Science, Dürnstein, Austria, Oct. 13-15, 2019 |
| A. Lapidoth | "An Information Theoretic Approach to Unequal Error Protection", Tel Aviv, Israel, Febr. 13-17, 2019 |
| | "All data are equal, but some data are more equal than others", Information Theory Society Distinguished Lecturer, Skopje, North Macedonia, April 7-8, 2019 |
| | "The additive noise channel with a helper", IEEE Information Theory Workshop (ITW), Visby, Sweden, Aug. 25-28, 2019 |
| | "Flash helping for additive-noise channels", Workshop on Mathematical Data Science, Dürnstein, Austria, Oct. 13-15, 2019 |

## 4.3 Local Lectures and Seminars by Invited Speakers

| | |
|---|---|
| April 2, 2019 | Thomas Heldt<br>*Model-based Signal Processing to Advance Neuromonitoring* |
| October 18, 2019 | Igal Sason<br>*Tight bounds on the Rényi entropy via majorization with applications to guessing and compression* |

# 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 | Information Theory Society Distinguished Lecturer |
| Hans-Andrea Loeliger | Executive Board Member, IEEE Transactions on Information Theory |
| | 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 |