Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Signal and Information Processing Laboratory (ISI)

Annual Report 2017

Signal and Information Processing Laboratory
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Foreword

by Hans-Andrea Loeliger

As every year, this report dryly lists some salient facts from the past year. What it cannot convey is what matters most: the excitement of research and the pleasure of working and learning together.

Concerning teaching, our last regular course in German has now been changed to English. Also, after much preparation, a new lab course on electronic circuits has successfully been introduced by Hampus Malmberg.

Our traditional hiking day led us to the Hirzli. As always, it was perfectly organized by Paddy Strebel. Thanks to Stefan Moser, we there had actually coffee from a moka pot.

It is always hard to part with PhD students that finish their PhD thesis and leave. This year, this happened with Nour Zalmai and with my external PhD student Carina Stritt, and my postdoc Jiun-Hung Yu moved on as well. On the other hand, we were happy to welcome two new PhD students, Robert Graczyk and Elizabeth Ren.

Contents

1 People

Professors:

Amos Lapidoth
Hans-Andrea Loeliger

Senior Researcher: Stefan Moser

Research Assistants / PhD Students:

Robert Gracyk
Tibor Keresztfalvi
Hampus Malmberg
Boxiao Ma
Murer Patrick
Christoph Pfister
Elizabeth Ren
Federico Wadehn
Jiun-Hung Yu (until Sept. 2017)
Nour Zalmai (until Sept. 2017)

Technical Staff: Patrik Strebel

Secretaries:

Rita Hildebrand
Silvia Tempel

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 (Master)
- *Signal and Information Processing: Modeling, Filtering, Learning,* Prof. Loeliger (Master)
- *Algebra and Error Correcting Codes,* Prof. Loeliger (Master)

Courses by external Lecturers:

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

2.2 Lab Courses

- *Fachpraktikum* (3 afternoons per week), Federico Wadehn
- *Blackfin DSP,* Boxiao Ma
- *Electronic Circuits and Signals Exploration Lab,* Hampus Malmberg

2.3 Student Projects

Student(s)	Title	Supervisor(s)

Semester Projects, Spring Term 2017

Student(s)	Title	Supervisor(s)
Henry Schulten	*Signal Quality Assessment for Intracranial Pressure Recordings*	Federico Wadehn, Hampus Malmberg
Dina Abdelhadi	*Finite Blocklength of the Continuous-time Poisson Channel*	Stefan Moser, Amos Lapidoth, Ligong Wang
Birkir Snaer Sigfusson	*A Synthetic Intracranial Pressure Signal Generator*	Federico Wadehn
Alessandro Pianezzi	*Performance Assessment and Extension on Image Segmentation with NUV-EM*	Boxiao Ma
Linus Rüttimann	*Saccade Detection via Sparse Input Estimation*	Federico Wadehn, David J. Mack

Semester Projects, Fall Term 2017

Student(s)	Title	Supervisor(s)
Tobias Keller	*Signal Processing Methods for Wind Speed Estimation*	Federic Wadehn, Hampus Malmberg
Robert Balas	*Tomographic Artifacts: Correction of Center of Rotation Displacement*	Boxiao Ma

Master Projects, Fall Term 2017

Student(s)	Title	Supervisor(s)
Armin Stierli	*Factor Graph Duality for a Convex Optimization Perspective on Linear Estimation*	Federic Wadehn
Thilo Weber	*Saccade and Smooth Pursuit Detection by Model-based Signal Separation*	Federico Wadehn, David J. Mack
Linus Rüttimann	*Tomographic Artifacts: Analysis, Simulation and Correction*	Boxiao Ma, Hampus Malmberg

3 Research

3.1 General Research Areas

Information Theory and Error Correcting Codes

- Multi-user information theory
- Network coding
- Combined source-channel coding
- Multi-path channels and fading channels
- 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

The Zero-undetected-error Capacity and the Sperner Capacity

Ahlswede, Cai, and Zhang proved that, in the noise-free limit, the zero-undetected-error capacity is lower bounded by the Sperner capacity of the channel graph, and they conjectured equality. We derive an upper bound that proves the conjecture.

At Low SNR Asymmetric Quantizers Are Better

We study the capacity of the discrete-time Gaussian channel when its output is quantized with a one-bit quantizer. We focus on the low signal-to-noise ratio (SNR) regime, where communication at very low spectral efficiencies takes place. In this regime a symmetric threshold quantizer is known to reduce channel capacity by a factor of $2/\pi$, i.e., to cause an asymptotic power loss of approximately two decibels. Here it is shown that this power loss can be avoided by using asymmetric threshold quantizers and asymmetric signaling constellations. To avoid this power loss, flash-signaling input distributions are essential. Consequently, one-bit output quantization of the Gaussian channel reduces spectral efficiency. Threshold quantizers are not only asymptotically optimal: at every fixed SNR a threshold quantizer maximizes capacity amont all one-bit output quantizers. The picture changes on the Rayleigh-fading channel. In the noncoherent case a one-bit output quantizer causes an unavoidable low-SNR asymptotic power loss. In the coherent case, however, this power loss is avoidable provided that we allow the quantizer to depend on the fading level.

The Zero-Error Feedback Capacity of State-Dependent Channel

One of the longest-standing open problems in Information Theory is to compute the zero-error capacity of a general discrete memoryless channel, i.e., the highest rate at which error-free communication is possible over the channel. Perhaps surprisingly, in the presence of feedback, this problem was solved by Shannon some 60 years ago. Unlike many other problems in Information Theory, the zero-error capacity becomes simpler in the presence of feedback. Motivated by this observation, we study the zero-error feedback capacity of state-dependent channels when the state information is revealed to the encoder either strictly-causally, causally, or non causally.

Correlated Sources over a Noisy Multiple-Access Channel

On the multiple-access channel (MAC), which models many-to-one communications, the source-channel separation does not always hold: it need not be optimal to describe the source sequences using bit streams of the rates that are optimal with respect to the allowed distortion and to then send the bits on the MAC with small probability of error. It is sometimes beneficial to exploit the correlation between the sources in order to build correlation between the transmitted symbols. If not optimal, how far from optimal is source-channel separation? To answer this question, we need lower bounds on the achievable distortions that hold for all transmission schemes and hence also for the optimal scheme. Finding such bounds is the aim of this project.

The Rate-and-State Capacity

The Rate-and-State capacity of a state-dependent channel with a state-cognizant encoder is the highest possible rate of communication over the channel when the decoder—in addition to reliably decode the data—must also reconstruct the state sequence with some required fidelity. Here we calculate this capacity in the presence of output-feedback, when the state reconstruction fidelity is measured using a single-letter distortion function and the state sequence is revealed to the encoder in one of two different ways: strictly-causally or causally.

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

Fundamentals and Applications of Factor Graphs

Factor graphs are a graphical notation for system models and algorithms in wide 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.

State-Space Methods for Signal Analysis

Most of our work in signal processing is based on linear state space models. Using IIR (infinite impulse response) models decouples the model order from the sampling rate and allows effortless transitions between discrete time and continuous time. We have extended such models to pulse-like (wavelet-like) signals that are localized anywhere in time. For given observations and unknown localization the corresponding model likelihood is then itself a function of time, i.e., a signal. The computation of such a likelihood signal leads to the concept of a likelihood filter (or feature detection filter), a generalization of a matched filter.

Multi-window Models and Recursive Model Fitting Beyond Least Squares

In an extension of state space methods, we have discovered the power of multi-sequence windows on the one hand and of polynomial cost functions beyond least squares.

Sparsity and Unsupervised Signal Decomposition

Normal priors with unknown variance (NUV) promote sparsity and blend well with expectation maximization (EM). For linear state space models, this approach can be used for estimating impulsive signals, detecting localized events, smoothing with occasional jumps in the state space, and for detecting and removing outliers. Combined with system identification (learning) by EM, this approach leads to very general and versatile methods for unsupervised signal detection, separation, and decomposition. The actual computations boil down to multivariate Gaussian message passing (i.e., variations of Kalman smoothing).

"Neural" Computation and Signal Processing

Likelihood filters (features detection filters) as above can be cascaded into a new sort of neural network. A key insight here is that such networks should internally work with spikes (sparse multichannel signals) rather than with continuous signals. The exploration of this approach has only just begun.

Imaging and Tomography

We also use NUV priors (see above) for images (in 2 or 3 dimensions). In particular, we use this technique for tomographic image estimation. The actual computations boil down to iterative scalar Gaussian message passing

Analog Computation and Analog-to-Digital Conversion

We have a long-standing interest in analog computation and analog circuits for information processing. Our recent research in this area has focused on analog-to-digital converters. However, some of our "neural" computation algorithms (see above) are easily implementable as analog circuits.

3.4 Publications

H.-A. Loeliger and P.O. Vontobel	"Factor graphs for quantum probabilities", IEEE Trans. on Information Theory, vol. 63, pp. 5642–5665, Sept. 2017.
Boxiao Ma, N. Zalmai, R. Torfason, C. Stritt, and H.-A. Loeliger	"Color image segmentation using iterative edge cutting, NUV-EM, and Gaussian message passing", 5th IEEE Global Conf. on Signal and Information Processing (GlobalSIP), Montreal, Canada, Nov. 14–16, 2017.
E. Ren, N. Zalmai, H.-A. Loeliger, and M. Stäger	"Multi-channel information processing for fire detection", 16th Int. Conf. on Automatic Fire Detection (Aube'17), Hyattsville, Maryland, USA, Sept. 12–14, 2017.
N. Zalmai, R. Keusch, H. Malmberg, and H.-A. Loeliger	"Unsupervised feature extraction, signal labeling, and blind signal separation in a state space world", 25th Europ. Signal Processing Conf. Kos, Greece, Aug. 28 – Sept. 2, 2017.
N. Zalmai, R. Wildhaber, and H.-A. Loeliger	"Autonomous state space models for recursive signal estimation beyond least squares", 25th Europ. Signal Processing Conf. (EUSIPCO), Kos, Greece, Aug. 28 – Sept. 2, 2017.

R. Wildhaber, N. Zalmai, M. Jacomet, and H.-A. Loeliger	"Signal detection and discrimination for medical devices using windowed state space filers", Int. Conf. on Biomedical Engineering (IASTED), Innsbruck, Austria, Feb. 20–21, 2017.
A. Bracher and A. Lapidoth	"Identification via the Broadcast Channel", IEEE Trans. on Information Theory, vol. 63, pp. 3480–3501, June 2017.
A. Bracher, A. Lapidoth, and Ch. Pfister	"Distributed task encoding", IEEE Int. Symposium on Information Theory, Aachen, Germany, June 25–30, 2017.
A. Lapidoth, S. Saeedi Bidokhti, and M. Wigger	"Dependence balance in multiple access channels correlated sources", IEEE Int. Symposium on Information Theory, June 25–30, 2017.
T. Kereszfalvi and A. Lapidoth	"Multiplexing zero-error and rare-error communications over a noisy channel with feedback", IEEE Int. Symposium on Information Theory, June 25–30, 2017.
F. Wadehn, M. Bohdanowicz, M. Czosnyka, and T. Heldt	"Non-invasive detection of intracranial hypertension using random forests", Computing in Cardiology, Rennes, France, Sept. 2017.
S. Moser	*How to Typeset Equations in LaTeX,* version 4.6., Sept. 2017.
S. Moser, M. Mylonakis, W. Ligong, and M. Wigger	"Asymptotic capacity results for MIMO wireless optical communication", IEEE Int. Symposium on Information Theory, June 25–30, 2017.
S. Moser, W. Ligong, and M. Wigger	"Asymptotic high-SNR capacity of MISO optical intensity channels", IEEE Information Theory Workshop, Kaohsiung, Taiwan, Nov. 6–10, 2017.

3.5 Completed PhD Theses

Nour Zalmai, *A State Space World for Detecting and Estimationg Events and Learning Sparse Signal Decompositions.* ETH Diss. 24360 (Prof. Loeliger).
Co-examiner: Prof. Bhaskar Rao, University of California, UC San Diego, USA.

Carina Stritt, *Assessment and Correction of Image Degradation in MeV Cone Beam Computed Tomography.* ETH Diss. 24546 (Prof. Loeliger).
Co-examiner: Prof. Stefan Kasperl, Fraunhofer-Institut für integrierte Schaltungen, Fürth, Germany.

4 Trips and Talks

4.1 Participation in Conferences and Meetings

Amos Lapidoth	IEEE Int. Symp. on Information Theory, Aachen, Germany, June 25–30.
	Int. ITG Conf. on Systems, Communications and Coding, Hamburg, Germany, Feb. 6–9.
	10th Asia–Europe Workshop on Concepts in Information Theory, Boppard, Germany, June 21–23.
H.-A. Loeliger	Information Theory and Applications Workshop, La Jolla, USA, February 12–17.
	IEEE Int. Symp. on Information Theory, Aachen, Germany, June 25–30.
Stefan Moser	IEEE Int. Symp. on Information Theory, Aachen, Germany, June 25–30.
	IEEE Information Theory Workshop, Kaohsiung, Taiwan, Nov. 6–10.
Boxiao Ma	5th IEEE Global Conf. on Signal and Information Processing, Montreal, Canada, Nov. 14–16.
Tibor Keresztfalvi	IEEE Int. Symp. on Information Theory, Aachen, Germany, June 25–30.
Hampus Malmberg	European Signal Processing Conference (EUSIPCO), Kos, Greece, Aug. 28 - Sept. 2.
Christoph Pfister	IEEE Int. Symp. on Information Theory, Aachen, Germany, June 25–30.
Federico Wadehn	Computing in Cardiology, Rennes, France, Sept. 24–27.
Reto Wildhaber	Int. Conf. on Biomedical Engineering, Innsbruck, Austria, Feb. 20–21.

4.2 Additional Lectures/Talks

H.-A. Loeliger	"Do NUV Priors Beat L1 Regularization? On Improper Priors, Interpolation, and Sparsity in Signal Processing", presented at the Information Theory and Applications Workshop, La Jolla, USA, February 12–17.
	"Estimation, Detection, and Sparsity with Linear State Space Models", presented at the Advanced Communications Center Annual Workshop & Feder Family Award, Tel Aviv University, February 22.
	"Estimation, Detection, Signal Separation, Sparsity, and Unsupervised Learning with Linear State Space Models", presented at DigiCosme Workshop on Information Theory, Telecom Paris Tech, October 12.

4.3 Local Lectures and Seminars by Invited Speakers

Jan. 9, 2017	Tobias Koch, Univ. Carlos III de Madrid, Leganes, Spain, *Rate-Distortion Bounds via "Duality" for Entropy-Constrained Scalar Quantization.*
May 11, 2017	Sergey Loyka, Univ. of Ottawa, Canada, *The Operational Capacity of Compound Uniformly-Ergodic Fading Channels.*
May 25, 2017	Bhaskar Rao, Univ. of California, San Diego, USA *Scale Mixture Modelling of Priors for Sparse Signal Recovery.*

5 Service Activities

5.1 Conference Organization

Amos Lapidoth	Co-Chair, 2018 International Zurich Seminar on Communications
Stefan Moser	Chair, 2018 International Zurich Seminar on Communications
	TPC Co-Chair, 2017 IEEE Information Theory Workshop, Kaohsiung

5.2 Other Service Activities

H.-A. Loeliger	Executive Board, IEEE Transactions on Information Theory
	President, ZuSem Fundation
Stefan Moser	Secretary, IEEE Switzerland Chapter on Digital Communication Systems