Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Signal and Information Processing Laboratory (ISI)

Annual Report 2018

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

by Amos Lapidoth

In the shadow of stupendous world events such as Prince Harry and Meghan Markle's wedding, we at ISI have continued to teach, mentor, supervise, and conduct research. While not quite as visible as the Royal Wedding, our efforts did not go unnoticed: a fair number of our research results were published in various journals and conference proceedings. Also noteworthy was the International Zurich Seminar (IZS'18) co-chaired by Stefan Moser and myself with tremendous support from Hans-Andrea Loeliger, Silvia Tempel, Paddy Strebel, and our friends in the Communication Technology Laboratory, in February 2018.

But all work and no play makes Jack a dull boy (and Jill a dull girl). We therefore participated in a fantastic hiking day to Stoos organized by Paddy Strebel. There we checked out the world's steepest cable railway. (We are, after all, engineers, and we get excited about such things.) The walk from Klingenstock to Fronalpstock offered amazing views, and the coffee that Stefan Moser prepared for us hit the spot.

The brave (crazy?) among us also enjoyed (much as one enjoys a terrifying roller coaster) a ski day at Engelberg, with chair lifts swinging uncontrollably from side to side. (No one will be surprised to learn that this excursion was also organized by Paddy Strebel.) Fortunately all returned happy and healthy.

Finally, we have also had a change of personnel in 2018, with Tibor Keresztfalvi leaving us (with a Ph.D. in hand) and with Raphael Keusch embarking on one. We wish him and all our students the best of luck, both at ETH and in the mountains.

Contents

1 People

Professors:	Amos Lapidoth Hans-Andrea Loeliger
Senior Researcher:	Dr. Stefan Moser
Research Assistants / PhD Students:	Robert Gracyk Tibor Keresztfalvi Raphael Keusch Boxiao Ma Hampus Malmberg Patrick Murer Christoph Pfister Elizabeth Ren Federico Wadehn Reto Wildhaber
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 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, Federico Wadehn
- *Blackfin DSP,* Boxiao Ma
- *Electronic Circuits and Signals Exploration Laboratory,* Hampus Malmberg

2.3. Student Projects

Student(s)	Title	Supervisor(s)

Semester Projects, Spring Term 2018

Cédric Bleuler	*Gambling and Rényi Divergence*	Amos Lapidoth, Christoph Pfister
Olafur Jon Thoroddsen	*Exploration of System Identification Methods for Acoustic Sensors*	Hampus Malmberg, Federico Wadehn
David Schmutz	*Topology Exploration for Locally Controlled Sampling Networks*	Hampus Malmberg

Semester Projects, Fall Term 2018

Felix Pfreundtner	*Blind Direct-to-reverberant Energy Ratio Estimation with Acoustic Onsets*	Elizabeth Ren, Ruksana Giurda
Stephan Meier	*State and Input Estimation in Large-Scale State-Space Models*	Federico Wadehn, Elizabeth Ren
Gabriel Stalder	*Image Deblurring Using a Piecewise Smooth Prior*	Boxiao Ma
Luxiao Cui	*3D Image Segmentation using Iterative Edge Cutting and a Piecewise Smooth Prior*	Boxiao Ma

Bachelor Group Project, Spring Term 2018

Alvin Pyngottu, Göktug Alkan, Jan Schäppi	*Sigma Delta Modulator Reconstruction using Neural Networks*	Hampus Malmberg, Raphael Keusch

Master Projects, Spring Term 2018

Jan-Philipp Schulze	*Anomaly Detection in Timeout Processes of Vehicles*	Elizabeth Ren, Arthur Mrowca (BMW), H.-A. Loeliger

Master Projects, Fall Term 2018

Olafur Jon Thoroddsen	*Multi-Path Analog-to-Digital Conversion*	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

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 Renyi entropy and the Arimoto-Renyi 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.

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 Mutiple-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 achiev distortions that hold 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 decthe 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 a large variety of fields including error correcting codes, signal processing, statistical physics, linear algebra, and more. We find factor grahs to be very helpful in most of our research work, and we continue to develop the approach.

State-Space Method 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 and 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. In this case, 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. Moreover, some of our „neural“ computation algorithms (see above) are easily implementable as analog circuits.

3.4 Publications

A. Bracher and A. Lapidoth	„The zero-error feedback capacity of state-dependent channels“, *IEEE Transactions on Information Theory*, vol. 64, January 2018
A. Lapidoth and S.I. Bross	„The rate-and-state capacity with feedback“, *IEEE Transactions on Information Theory,* vol. 64, January 2018
A. Lapidoth and C. Pfister	„Testing against independence and a Rényi information measure“ in *Proceedings 2018 IEEE Information Theory Workshop* (ITW), Guangzhou, China, Nov. 25-29, 2018, pp. 1-5
H.-A. Loeliger, B. Ma, H. Malmberg and F. Wadehn	„Factor graphs with NUV priors and iteratively reweighted descent for sparse least squares and more“, *Int. Symposium on Turbo Codes and Iterative Information Processing* (ISTC) 2018, Hongkong, China, Dec. 3-7, 2018
B. Ma, N. Zalmai and H.-A. Loeliger	„A multi-resolution approach to complexity reduction in tomographic reconstruction“, *2018 IEEE Int. Conf. on Acoustics, Speech and Signal Processing* (ICASSP), Calgary, Canada, April 15-20, 2018
F. Wadehn, D.J. Mack, E. Keller and T. Heldt	„A multiscale intracranial pressure signal simulator“, *Computing in Cardiology* (CinC), Maastricht, Netherlands, Sept. 2018
F. Wadehn, D.J. Mack, T. Weber and H.-A. Loeliger	„Estimation of neural inputs and detection of saccades and smooth pursuit eye movements by sparse Bayesian learning“, *Int. Conf. of the IEEE Engineering in Medicine and Biology Society (EMBC*), Honolulu, Hawaii, USA, Aug. 2018
J.-H. Yu and H.-A. Loeliger	„Simultaneous partial inverses and decoding interleaved Reed-Solomon codes“. *IEEE Trans. Inform. Theory*, vol. 64, pp. 7511-7528, Dec. 2018
L. Li, S.M. Moser, L. Wang and M. Wigger	„The MISO free-space optical channel at low and moderate SNR“, in *Proceedings 52nd Annual Conference on Information Sciences and Systems* (CISS'18), Princeton University, Princeton, NJ, USA, Mar. 2-23, 2018, pp. 1-6
L. Li, S.M. Moser, L. Wang and M. Wigger	„On the capacity of MIMO optical wireless channels“, in *Proceedings 2018 IEEE Information Theory Workshop* (ITW'18), Guangzhou, China, Nov. 25-29, 2018, pp. 26-30
H.Y. Lin, S.M. Moser and P.N. Chen	„The r-wise Hamming distance and its operational interpretation for block codes“, in *Proceedings 52nd Annual Conference on Information Sciences and Systems* (CISS'18), Princeton University, Princeton, NJ, USA, Mar. 2-23, 2018, pp. 1-6

H.Y.Lin, S.M. Moser and P.N. Chen — „Weak fip codes and their optimality on the binary erasure channel“, *IEEE Transactions on Information Theory*, vol. 64, no. 7, pp. 5191-5218, July 2018

H.Y. Lin, S.M. Moser and P.N. Chen — „Connections between the error probability and the r-wise Hamming distances“, in *Proceedings 2018 International Symposium on Information Theory and its Applications* (ISITA’18), Singapore, Oct. 28-31, 2018

R.A. Wildhaber, N. Zalmai, M. Jacomet and H.-A. Loeliger — „Windowed state-space filters for signal detection and separation“, *IEEE Trans. on Signal Processing*, vol. 66, no. 14, pp. 3768-3783, July 15, 2018

R.A. Wildhaber, D. Bruegger, N. Zalmai, H. Malmberg, J. Goette M. Jacomet, H. Tanner, A. Haeberlin and H.-A. Loeliger — „Estimation of the cardiac field in the esophagus using a multipolar esophageal catheter“, *IEEE Transactions on Biomedical Circuits and Systems*.

S.M. Moser — *Advanced Topics in Information Theory (Lecture Notes),* 3rd edition, Signal and Information Processing Laboratory ETH Zürich, Switzerland, and Institute of Communications Engineering, National Chiao Tung University (NCTU), Hsinchu, Taiwan, 2018. Online available: http://moser-isi.ethz.ch/scripts.html

S.M. Moser — *Information Theory (Lecture Notes),* 6th edition, Signal and Information Processing Laboratory, ETH Zürich, Switzerland, and Institute of Communications

Engineering,

National Chiao Tung University (NCTU), Hsinchu, Taiwan, 2018. Online available: http://moser-isi.ethz.ch/scripts.html

S.M. Moser, L. Wang and M. Wigger — „Capacity results on multiple-input single-output wireless optical channels“, *IEEE Transactions on Information Theory,* vol. 64, no. 11, pp. 6954-6966, November 2018

T. Keresztfalvi and A. Lapidoth — „Multiplexing zero-error and rare-error communications over a noisy channel“, to appear in *IEEE Transactions on Information Theory*

T. Keresztfalvi und A. Lapidoth — „Partially-robust communications over a noisy channel“, in *Proceedings 2018 IEEE International Symposium on Information Theory (ISIT)*, Vail, USA, June 17-22, 2018, pp. 2003-2006

3.5 Completed PhD Theses

Tibor Keresztfalvi, *Some Data are More Important than Others.* ETH Diss. 25430 (Prof. Lapidoth). Co-examiner: Prof. Osvaldo Simeone, King’s College London, UK

4 Trips and Talks

4.1 Participation in Conferences and Meetings

H.-A. Loeliger	ITA 2018, Information Theory and Applications Workshops, La Jolla, CA, USA, February 11-16, 2018
H.-A. Loeliger	IEEE International Symposium on Information Theory (ISIT), Vail, Colorado, USA, June 17-22, 2018
H.-A. Loeliger	International Symposium on Turbo Codes & Iterative Information Processing, Hongkong (ISTC 2018), Dec. 3-7, 2018
Boxiao Ma Signal 15-	International Conference on Acoustics, Speech and Processing, ICASSP, Calgary, Alberta, Canada, April 20, 2018
Boxiao Ma	International Symposium on Turbo Codes & Iterative Information Processing, Hongkong, Polytechnic University, Dec. 3-7, 2018
Federico Wadehn Engineering USA,	40th International Conference of the IEEE in Medicine and Biology Society (EMBC), Honolulu, July 17-21, 2018
Federico Wadehn Holland,	Computing and Cardiology (CinC), Maastricht, Sept. 23-26, 2018
Amos Lapidoth	Tel Aviv, Israel, April 25-30, 2018
Amos Lapidoth	ISIT 2018 in Vail, Colorado, USA, June 16-26, 2018
Amos Lapidoth	WiAd London, UK, June 26-July 1, 2018
Amos Lapidoth	ICSEE 2018, Eilat, Israel Dec. 9-16, 2018
Stefan Moser	ISIT 2018, Vail, Colorado, USA, June 15-22, 2018
Christoph Pfister	ITW 2018 in Guangzhou, China, Nov. 23-Dec. 1, 2018
Tibor Keresztfalvi	ISIT 2018, Vail, Colorado, USA, June 15-22, 2018
Robert Graczyk	ISIT 2018, Vail, Colorado, USA, June 15-22, 2018
Robert Graczyk	ICSEE 2018, Eilat, Israel, Dec. 11-16, 2018

4.2 Additional Lectures/Talks

H.-A. Loeliger	„Feature learning with state space models and pulse domain signal analysis“, presented at the Information Theory and Applications Workshop, La Jolla, USA, February 11-16, 2018
A. Lapidoth	„Sit back and enjoy the noise“. Plenary talk at International Symposium on Information Theory 2018, June 16-26, 2018

4.3 Local Lectures and Seminars by Invited Speakers

May 18, 2018	Yonatan Gutman, *Metric mean dimension and almost lossless analog compression*
October 4, 2018	Jonathan Rosenthal, about his own chess engine
October 10, 2018	Meir Feder, *Information Theory of the Learnable*

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
	Publications Chair, International Symposium on Information Theory 2018

5.2 Other Service Activities

Hans-Andrea Loeliger	Executive Board Member, IEEE Transactions on Information Theory
	President, ZuSem Fundation
Stefan Moser	Secretary, IEEE Switzerland Chapter on Digital Communication Systems