Signal and Information Processing Laboratory

Prof. A. Lapidoth and Prof. H.-A. Loeliger

ANNUAL REPORT

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Foreword

Apparently the designation of this year as 2016 is due to Dionysius Exiguus and was generally accepted by the early ninth century. Be that as it may, 2016 is on even number, so the task of writing this introduction fell on yours-truly and, more importantly, this was a year in which our Institute hosted the International Zurich Seminar.

It was a good year for our Institute – which is to say that for faculty, students, and staff alike it was engaging and productive. Stefan Moser and I co-chaired the twenty-fourth International Zurich Seminar on Communications with tremendous support from Andi Loeliger, Patrik Strebel, Silvia Tempel, Rita Hildebrand, and from our colleagues at NARI Helmut Bölcskei and Michael Lerjen. We reconnected with colleagues from the world over at the Hotel Zurichberg, enjoying the science, company, and the views.

We also enjoyed our annual Wandertag, ably led by Patrik Strebel, as well as a Skitag led by you-guessed-it-right Patrik Strebel. Our ISI Christmas Dinner took place a Restaurant Nachtjäger (heartily recommended for its excellent Schmorbraten) in the company of current and past colleagues and even some lively but well-behaved offsprings.

2016 brought a few changes as well. Three new doctors were minted: Dr. Sarah Neff, Dr. Christian Schürch and Dr. Annina Bracher. All three have found positions in industry in or near Zurich. We are glad to have them close by, and we wish them all the best in their future careers.

I would also like to thank and congratulate Thomas Schärer, who has taught his final lab course. Future students will not, alas, be able to profit from his top-notch tuition as have their predecessors (for the last 16 years) which is their loss. Our loss is that of a valued colleague. Thank you, Thomas, for your time, dedication and willingness to work past the regular age of retirement!

I end this short introduction secure in the knowledge that everyone who reads it understands that its length is inversely proportional to the depth of the gratitude I feel to the many individuals whose time and energy make the institute such a wonderful place. May we continue to flourish!

Amos Lapidoth

Contents

1. Personnel

Professor for Information Theory:

Prof. Amos Lapidoth

Professor for Signal Processing:

Prof. Hans-Andrea Loeliger

Secretaries:	**Rita Hildebrand**	
	Silvia Tempel	
Senior Researcher:	**Dr. Stefan Moser**	
Research Assistants:	**Annina Bracher**	Msc ETH (left on 31.8.2016)
	Tibor Keresztfalvi	MSc ETH
	Hampus Malmberg	MSc ETH
	Boxiao Ma	MSc ETH
	Sarah Neff	MSc ETH (left on 31.8.2016)
	Murer Patrick	MSc ETH
	Christoph Pfister	MSc ETH
	Christian Schürch	MSc ETH (left on 31.8.2016)
	Federico Wadehn	MSc ETH
	Georg Wilckens	MSc ETH (left on 30.6.2016)
	Jiun-Hung Yu	MSc NCTU Taiwan
	Zalmai Nour	MSc ETH
Technical Staff:	**Thomas Schärer**	(left on 31.12.2016)
	Patrik Strebel	El. Eng. HTL

2. Teaching

2.1 Courses

Sem.	Instructors	Title	ETH-No.
5th	Prof. H.-A. Loeliger	Zeitdiskrete und statistische Signal-verarbeitung	227-0101
7th	Prof. H.-A. Loeliger	Signal and Information Processing	227-0427
8th	Prof. H.-A. Loeliger	Algebra and Error Correcting Codes	227-0418
6th	Prof. A. Lapidoth	Communication and Detection Theory	227-0104
7th	Prof. A. Lapidoth	Information Theory I	227-0417
8th	Prof. A. Lapidoth	Information Theory II	227-0420

Courses by external Lecturers

7th	Dr. K. Heutschi	Accoustics I	227-0477
8th	Dr. K. Heutschi	Accoustics II	227-0478
7th	Dr. H.P. Schmid	Analog Signal Processing and Filtering	227-0478

2.2 Lab Courses (Practica)

5/6th	Practica	Laboratory for "Fundamentals in Electrical Engineering"	227-0095/96
3rd/4th	Ch. Schürch	Blackfin DSP	227-0085
2nd/3rd	Th. Schaerer	EMG Biofeedback Device	227-0085

2.3 Student Projects

Students	Title	Supervisor
Semester Projects FS 2016		
Robert Graczyk	Hierarchical Input Estimation	Nour Zalmai
Julien Finaz	Sequential Monte Carlo Methods for Inference on Graphical Models	Mehdi Molkaraie
Michael Weigelt	Click Sound Detection in Background Noise Environment	Nour Zalmai
Semester Projects HS 2016		
Robert Torfason	Graph Cuts with NUV-EM and Gaussian Message Passing	Federico Wadehn Boxiao Ma
Michael Hersche	Automatic Ultrasound Tracing in Cerebral Blood Flow Velocity Recordings	Federico Wadehn Boxiao Ma
Matthias Heinzmann	Continous-Time and Hybrid Kalman Filtering and Smoothing: New Implementations	Federico Wadehn Hampus Malmberg
Martin Lendi	Binary-Input Estimation for Linear Gaussian Models	Nour Zalmai Hampus Malmberg
Zixuan Peng	Robust Click Sound Recognition in Background Noise Environment	Nour Zalmai Reto Wildhaber
Bachelor Student Projects		
Cecilia D'Errico Samuele Darani	Pidroponics: Automatic Hydroponic Cultivation with Pi(es)	Hampus Malmberg Nour Zalmai
Kian Hunziker Jonathan Kakon Paul Lehmann	A Digital Modular Synthesizer	Patrick Murer Hampus Malmberg

Master Theses 2016

Michael Purghart	Cascaded Analog-to-digital Conversion for Bandpass Sampling	Hampus Malmberg
Vijay Sahdeva	Numerically Stable and Efficient Variations of Message Passing in Linear Gaussian State Space Models	Hampus Malmberg
Raphael Keusch	Blind Signal Separation by Automatic State Space Model Selection and Learning	Nour Zalmai Hampus Malmberg
Timon Samuel Künzle	A State-Space Approach to Multi-Channel Source Localization	Nour Zalmai Reto Wildhaber
Michail Mylonakis	Capacity Bounds for the MIMO Free-space Optical Intensity Channel	Stefan Moser Amos Lapidoth
Elizabeth Ren	Multi-channel Information Processing for Fire Detection and Classification	Nour Zalmai Dr. Mathias Stäger
Dario Walser	Non-invasive Intracranial Pressure Estimation	Federico Wadehn H.-A. Loeliger

Research

3.1. General Research Areas

The Signal and Information Processing Lab focusses on research and teaching in the following areas:

Information Theory and Coding

Information theory, error correcting codes, and their application to communication systems. Current topics:

- Combined source-channel coding for multi-access networks
- Multi-access channels with noisy feedback
- Network coding
- Capacity of fading channels
- Broadcasting correlated sources
- Multi-path channels
- Interference networks
- Optical channels
- Error correcting codes
- Monte Carlo algorithms and numerical information theory

Digital Signal Processing

Current topics:

- Fundamentals and applications of graphical models (factor graphs)
- State-space methods in signal processing
- Sparsity and unsupervised signal decomposition
- "Neural" computation
- Imaging and tomography

Analog and Hybrid Signal Processing

Current topics:

- Analog-to-digital conversion
- "Neural" computation

3.2 Current Research Topics

Prof. Amos Lapidoth (Information Theory)

Maximum Renyi Entropy Rate

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 decoding 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.

Prof. H.-A. Loeliger (Signal Processing)

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 graphs to be very helpful in most of our research work, and we continue to develop the approach. Recent progress includes localized state space models (see below), and factor graphs for quantum-mechanical systems.

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.

In parallel with the development of this approach, we have applied it to applications including joint symbol synchronization and matched filtering, detection of seismic waves, analysis of various biomedical signals, gesture detection using the magnetic sensor in smartphones, and many more. See also the topics below.

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 separation and decomposition. The actual computations boil down to multivariate-Gaussian message passing (i.e., variations of Kalman smoothing).

"Neural" Computation

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.

Error Correcting Codes

Our present interest is in a new perspective on decoding algorithms for Reed-Solomon codes and some related codes, and on combining ideas from Reed-Solomon codes and polar codes.

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.

3.3 Publications

H.-A. Loeliger, L. Bruderer, H. Malmberg, and N. Zalmai
"On sparsity by NUV-EM, Gaussian message passing, and Kalman smoothing", *Information Theory and Applications Workshop (ITA),* La Jolla, CA, January 31 – February 5, 2016.

Ch. Schürch
"A partial order for the synthesized channels of a popular code" , *IEEE International Symposium on Information Theory (ISIT),* Barcelona, Spain, July 10 – 15, 2016.

F. Wadehn, L. Bruderer, V. Sadehva, and H.-A. Loeliger
"Square-root and diagonalized Kalman smoothers", *54th Annual Allerton Conference on Communication, Control, and Computing,* University of Illinois at Urbana, Champaign, USA, September 27 – 30, 2016.

F. Wadehn, V. Sahdeva, Bruderer, H. Yu, J. Dauwels, and H.-A. Loeliger
"Outlier-insensitive Kalman Smoothing and Marginal L. Message Passing", *24th European Signal Processing Conference (EUSIPCO),* Budapest, Hungary, August 29 – September 2, 2016.

Jiun Hung Yu and H.-A. Loeliger
"Partial inverses mod m(x) and reverse Berlekamp-Massey decoding", *IEEE Transactions on Information Theory,* Issue 12, Vol. 62, pp. 6737 – 6756, December 2016

N. Zalmai, C. Luneau, C. Stritt, and H.-A. Loeliger
"Tomographic reconstruction using a new voxel-domain and prior and Gaussian message passing", 24th European Signal Processing Conference (EUSIPCO), Budapest, Hungary, August 29 – September 2, 2016.

N. Zalmai, H. Malmberg, and H.-A. Loeliger
"Blind deconvolution of sparse but filtered pulses with linear state space models", *41th IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP),* Shanghai, China, March 20 – 25, 2016.

N. Zalmai, R. Wildhaber, D. Clausen, and H.-A. Loeliger
"Inferring depolarization of cells from 3D-electrode measurements using a bank of linear state space models", *41th IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP),* Shanghai, China, March 20 – 25, 2016.

A. Bracher and A. Lapidoth
"The zero-error capacity of the Gelfand-Pinsker channel with a feedback link", *IEEE International Symposium on Information Theory (ISIT)*, pp.1272 – 1276, July 10 – 15, 2016.

S. Bross and A. Lapidoth	"Conveying data and state with feedback", *IEEE International Symposium on Information Theory (ISIT)* pp. 1277 – 1281, July 10 – 15, 2016.
S. Bross and A. Lapidoth	"The Gaussian state-dependent channel with rate-limited decoder state-information", *International Conference on the Science of Electrical Engineering (ICSEE),* Eilat, Israel, November 16 – 18, 2016.
A. Lapidoth	"Fun with feedback and various notions of channel capacity, *International Conference on the Science of Electrical Engineering (ICSEE),* Eilat, Israel, November 1 – 18, 2016.
M. Wigger and A. Lapidoth	"A necessary condition for the transmissibility of correlated sources over a MAC", *IEEE International Symposium on Information Theory (ISIT),* pp. 2024 – 2028, July 10 – 15, 2016.
A. Lapidoth and M. Wigger	"Conditional and Relevant Common Information", *International Conference on the Science of Electrical Engineering (ICSEE),* Eilat, Israel, November 16 – 18, 2016.
A. Lapidoth and Ch. Pfister	"Two measures of dependence", *International Conference on the Science of Electrical Enginering" (ICEE), Eilat, Israel, November 16 – 18, 2016.*
Ch. Bunte and A. Lapidoth	"Maximum Rényi Entropy Rate", *Transaction on Information Theory,* vol. 62, pp. 1193 – 1205, March 2016.

3.4 Completed PhD Theses

SCHUERCH Christian

On Successive Cancellation Decoding of Polar Codes and Related Code
ETH-Diss. Nr. 23608

Referee:	Prof. Hans-Andrea Loeliger
Co-examiner:	Prof. Henry Pfister, Duke University, Durham, USA

NEFF Sarah

A New Approach to Information Processing with Filters and Pulses
ETH-Diss. Nr. 23672

Referee.:	Prof. Hans-Andrea Loeliger
Co-examiner:	Prof. Dr. Giacomo Indiveri, Universität Zürich

BRACHER Annina

Identification and Zero-Error Codes
ETH-Diss. Nr. 23698

Referee: Prof. Amos Lapidoth

Co-examiner: Prof. Dr. Holger Boche, Institute of Theoretical Information Technology, Tu Munich, Germany

4. Trips and Talks

4.1 Participation in Conferences and Meetings

Lapidoth Amos	IEEE International Symposium on Information Theory, Barcelona, Spain, July 10 – 15.
Bracher Annina	IEEE International Symposium on Information Theory, Barcelona, Spain, July 10 – 15.
Lapidoth Amos	International Conference on the Science of electrical engineering, Eilat, Israel, November 16 – 18.
Pfister Christoph	International Conference on the Science of electrical engineering, Eilat, Israel, November 16 – 18.
Keresztfalvi Tibor	European School of Information Theory, Gothenburg, Sweden, April 2 – 10.
Nour Zalmai	41st IEEE International Conference on Acoustics, Speech and Signal Processing, Shanghai, China, March 20 – 25.
Malmberg Hampus	41st IEEE International Conference on Acoustics, Speech and Signal Processing, Shanghai, China, March 20 – 25.
Nour Zalmai	European Signal Processing Conference, Budapest, Hungary, August 29 – September 2.
Wadehn Federico	European Signal Processing Conference, Budapest, Hungary, August 29 – September 2.
Wadehn Federico	IEEE Engineering in Medicine and Biology Society, Orlando, Florida, August, 16 – 20.
Wadehn Federico	54th Annual Allerton Conferece on Communication, Control and Computing, Urbana, Champaign, September 27 – 30.
Schürch Christian	IEEE International Symposium on Information Theory, Barcelona, Spain, July 10 – 15.
Loeliger Hans-Andrea	Information Theory and Applications Workshop, La Jolla, USA, January 31 – February 5.
Loeliger Hans-Andrea	IEEE International Symposium on Information Theory, Barcelona, Spain, July 10 – 15.
Moser Stefan	IEEE International Symposium on Informtion Theory, Barcelona, Spain, July 10 – 15.
Moser Stefan	National Chiao Tung University, Hsinchu, Taiwan, April 30 – May 3.

4.2 Invited Lectures and Seminars

01.03.2016	**Dr. Shlomo Shamai,** Israel Institute of Technology, Technion, Haifa, Israel "Compressive sensing in coding problems: A rigorous information theoretic approach"
12.09.2016	**Dr. Justin Dauwels**, School of Electrical & Electronics Engineering, Nanyang Technological University, Singapore "Variational Bayes learning of graphical models with hidden variables"
07.10.2016	**Dr. Justin Dauwels**, School of Electrical & Electronics Engineering, Nanyang Technological University, Singapore "Variational Bayes learning of time-varying graphial models"

5. Service Activities

5.1 Conference Organization

Prof. Lapidoth	Co-Chair, 2016 International Zurich Seminar on Communications
Dr. Moser	-Chair, 2016 International Zurich Seminar on Communications

5.2 Other Service Activities and Society Memberships

Prof. Lapidoth	Fellow of the IEEE Member of the Center for Communication and Information Technologies (CCIT), Technion, Haifa, Israel
Prof. Loeliger	Fellow of the IEEE Member of the Executive Board of the IEEE Transactions on Information Theory
Dr. Moser	Secretary, IEEE Switzerland Chapter on Digital Communication System