Signal and Information Processing Laboratory

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

ANNUAL REPORT

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Foreword

Again, we are grateful for the stable environment at ETH that allows us to do meaningful research and to teach as best as we can. All was not stable, though: the department is pressed for office space and we had to give some of ours, which caused a lot of work for Paddy Strebel.

The same Paddy, among other things, also organized a fantastic skiing day in Davos and a very pleasant summer hike to the Caumasee, and he prepared a new registration software for the upcoming 2016 Zurich Seminar, which turned out to work perfectly.

Inevitably, there are some other changes as well: Lukas Bruderer finished his PhD and left us in January, an a new PhD student, Tibor Keresztfalvi, joined us in November.

As every year, the present report dryly lists some of our research topics and papers, but it cannot convey our excitemet about what we do. If you want to experience that, come and visit!

Hans-Andrea Loeliger

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
	Lukas Bruderer	MSc ETH (left on 31.1.2015)
	Tibor Keresztfalvi	MSc ETH
	Hampus Malmberg	MSc ETH
	Sarah Neff	MSc ETH
	Christian Schürch	MSc ETH
	Federico Wadehn	MSc ETH
	Georg Wilckens	MSc ETH
	Jiun-Hung Yu	MSc.NCTU Taiwan
	Zalmai Nour	MSc.ETH
Technical Staff:	**Thomas Schärer**	
	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 2015		
Gabrielle Buytaert	Solving Superpositions with Sparse Input Estimation	Nour Zalmai Hampus Malmberg
Michail Mylonakis	A Study of Algorithms for System Identification	Nour Zalmai Hampus Malmberg
Dario Walser	Sparse Input Estimation for Heart Beat Detection in Ballistocardiogram Recordings	Hampus Malmberg Federico Wadehn
Semester Projects HS 2015		
Vijay Sahdeva	Marginal Backward Message Passing and Outlier Insensitive Kalmann Smoother	Federico Wadehn
Michael Jost	Reconstruction Algorithms for Computed 2-D Tomography	Nour Zalmai Federico Wadehn
Raphael Urs Keusch	Reconstructing Non-Uniformly Sampled Biosignals	Hampus Malmberg Reto Wildhaber
Armin Stierli	Outlier Insensitive Nonlinear Filtering and Smoothing	Federico Wadehn
Master Theses 2015		
Désirée Clausen	Source Localization of Cardiac Depolarization from Multi-Channel Esophageal ECG Recordings	Nour Zalmai Reto Wildhaber
Andreas Büchel	Gesture Recognition using Accelero-meter and Gyroscope Measurement	Nour Zalmai Sarah Neff
Patrick Murer	Implementation of a Staircase Code for Optical Communication	Christian Schürch
Clément Luneau	Tomographic Reconstruction by Scalar Gaussian Message Passing	Nour Zalmai Carina Stritt

3. 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
- Interference networks
- Optical channels
- Error correcting codes
- Monte Carlo algorithms and numerical information theory

Digital Signal Processing

Current topics:

- State-space methods in signal processing
- Fundamentals and applications of graphical models (factor graphs)
- Feature detection filters

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 supremum of the Renyi entropy rate over the class of discrete-time stationary stochastic processes whose marginals are supported by some given set and statisfy some given cost constraint is studied. Unlike the Shannon entropy, the Renyi entropy of a random vector can exceed the sum of the Renyi entropies of its components, and the supremum is therefore typically not achieved by memoryless processes. It is nonetheless related to Shannon's entropy: When the Renyi parameter exceeds one the supremum is equal to the corresponding supremum of Shannon's entropy, and when it is smaller than one the supremum equals the logarithm of the volume of the support set.

Covering Point Proccesses

An encoder observes a point pattern in an interval and wishes to describe it to a reconstructor using bits. Based on these bits, the reconstructor wishes to select a subset of the interval that is guaranteed to contain all the points in the pattern. For this scenario we study the trade-off between the Lebesgue measure of the subset and the number of description bits (normalized by the intervals's length). We also consider a Wyner-Ziv version of this problem where some of the points in the pattern are known to the reconstructor.

Feedback, Cribbing, and Strictly-Causal State-Information on the Multiple-Access Channel

It is shown that the capacity region of the multiple-access channel (MAC) with feedback is contained in that of the MAC without feedback but with strictly-causally cribbing encoders. This outer bound is tight when each encoder can compute the symbol produced by the other encoder based on its own symbol and on the channel output. For some channels, this bound is tighter than the Dependence-Balance Bound. It is also shown that feedback does not increase the capacity region of the MAC with cribbing encoders.

For a state-dependent MAC with cribbing encoders, we show that strictly-causal state-information at the encoders does not increase the capacity region. This is used to derive a new outer-bound on the capacity region of the state-dependent MAC with strictly-causal common state-information. The capacity region of the state-dependent DM-MAC with cribbing encoders is not enlarged even if both feedback and strictly-causal state-information are furnished to the encoders.

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.

Constrained Source Coding with Side Information

The source-coding problem with side information at the decoder is studied subject to a constraint that the encoder – to whom the side information is unavailable – be able to compute the decoder's reconstruction sequence to within some distortion. For descrete memoryless sources and finite single-letter distortion measures, an expression is given for the minimal description rate as a function of the joint law of the source and side information and of the allowed distortions at the encoder and at the decoder. The minimal description rate is also computed for a memoryless Gaussian source with squared-error distortion measures. A solution is also provided to a more general problem where there are more than two distortion constraints and each distortion function may be a function of three arguments: the source symbol, the encoder's reconstruction symbol, and the decoder's reconstruction symbol.

Cognitive Wyner Networks with Clustered Decoding

We study an interference network where equally-numbered transmitters and receivers lie on two parallel lines, each transmitter opposite its intended receiver. We consider two short-range interference models: the "asymmetric network", where the signal sent by each transmitter is interfered only by the signal sent by its left neighbor (if present), and a "symmetric network", where it is interfered by both its left and its right neighbors.

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.

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

State-Space Methods in Statistical Signal Processing

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 biomedical signals, gesture detection using the magnetic sensor in smartphones, and many more.

Likelihood filters (features detection filters) can also be cascaded into a new sort of neural network that works naturally with multichannel signals at multiple time scales. The exploration of this new approach has only just begun.

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 above), and factor graphs for joint probability distributions in quantum system with many variables.

Monte Carlo Algorithms and Numerical Information Theory

Many hard computational problems in information theory and statistical estimation can be addressed with Monte Carlo techniques. We have been continuing to enlarge the scope of such algorithms, e.g., to computing the partition function of Markov random fields at low temperature using factor graph duality.

Error Correcting Codes

Our present interest is in a new perspective on decoding algorithms for Reed-Solomon codes (and similar codes), and on combining ideas from Reed-Soloon 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, many of our likelihood filters (see above) are easily implementable as analog circuits.

3.3 Publications

H.-A. Loeliger and G. Wilckens	"Control-based analog-to-digital conversion without sampling and quantization", *Information Theory and Applications Workshops, (ITA),* La Jolla, CA, February 1 – 6, 2015.
S. Marano, D. Fäh, and H.-A. Loeliger	"A state-space approach for the analysis of wave and diffusion fields", *40th IEEE International Conference on Acoustics Speech and Signal Processing,* Brisbane, Australia, April 19 – 24, 2015.
H.-A. Loeliger and S. Neff	"Pulse-domain signal parsing and neural computation", *IEEE International Symposium on Information Theory,* Hongkong, China, June 14 - 19, 2015.
F. Wadehn, D. Carnal, and H.-A. Loeliger	"Estimation of Heart Rate and Heart Rate Variability from Pulse Oximeter Recordings using Localized Model Fitting", *37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Milan, Italy,* August 25 – 29, 2015.
F. Wadehn, Y. Zhao, and H.-A. Loeliger	"Heart Rate Estimation in Photoplethysmogram Signals using Nonlinear Model-Based Preprocessing", *Computing in Cardiology*, Nice, France, September 6 – 9, 2015.
F. Wadehn, L. Bruderer, and H.-A. Loeliger	"Sparse-input detection algorithm with applications in electrocardiography and ballistocardiography", *8th International Conference on Bio-Inspired Systems and Signal Processing,* Lisbon, Portugal, January 12 – 15, 2015.
Jiun Hung Yu and H.-A. Loeliger	"Decoding of interleaved Reed-Solomon codes via simultaneous partial inverses", *IEEE International Symposium on Information Theory,* Hongkong, China, June 14 – 19, 2015.
S. Diether, L. Bruderer, A. Streich, and H.-A. Loeliger	"Efficient blind estimation of subband reverberation time from speech in non-diffuse environments", *40th IEEE International Conference on Acoustics, Speech and Signal Processing,* Brisbane, Australia, April 19 – 24, 2015.
L. Bruderer, H. Malmberg, and H.-A. Loeliger	"Deconvolution of weakly-sparse signals and dynamical-system identification by Gaussian message passing", *IEEE International Symposium on Information Theory,* Hongkong, China, June 14 – 19, 2015.

N. Zalmai, C. Kaeslin, L. Bruderer, S. Neff, and H.-A. Loeliger	"Gesture recognition from magnetic field measurements using a bank of linear state space models and local likelihood filtering", *40th IEEE International Conference on Acoustics, Speech and Signal Processing,* Brisbane, Australia, April 19 – 24, 2015.
F. Wadehn, K. Schieban, and K. Nikolic	"Motion Sensitivity Analysis of Retinal Ganglion Cells in Mouse Retina Using Natural Visual Stimuli", *37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, Milan, Italy, August 25 – 29, 2015.
C. Pfister and A. Lapidoth	"A Method for the Construction of Optimal Task Encoders", *IEEE International Symposium on Information Theory,* Hongkong, China, June 14 – 19, 2015.
Chen-Po Ning, Lin Hsuan-Yin, and S. Moser	"A Closed-Form Expression for the Exact Average Error Probality of Arbitrary Binary Codes over the Binary Erasure Channel", *IEEE Joint Workshop on Information Theory and and Communications*, Hualien, Taiwan, January 22 – 23, 2015.
S. Krajci, Liu Chin-Fu, M. Ladislav, and S. Moser	"Performance Analysis of Fano Coding", *IEEE International Symposium on Information Theory,* pp. 1746 – 1750, June 14 – 19, 2015.
Chen-Po Ning, Lin Hsuan-Yin, and S. Moser	"Nonlinear Codes Outperform the Best Linear Codes on the Binary Erasure Channel", *IEEE International Symposium on Information Theory*, pp. 1751 – 1755, June 14 – 19, 2015.

3.4 Completed PhD Theses

BRUDERER Lukas Alex

Input Estimation and Dynamical System Identification: New Algorithms and Results

ETH-Diss. Nr. 22575

Referee: Prof. Hans-Andrea Loeliger

Co-examiner: Prof. Bernard Fleury, Aalborg University, Denmark

4. Trips and Talks

4.1 Participation in Conferences and Meetings

Lapidoth Amos	BIU Engineering Colloquium, Bar-Ilan University, Tel-Aviv, Israel, February 2 – 15.
Lapidoth Amos	IEEE Information Theory Workshop, Jerusalem, Israel, April 26 – May 3.
Lapidoth Amos	IEEE International Symposium on Information Theory, Hongkong, China, June 14 – 19.
Bracher Annina	IEEE International Symposium on Information Theory, Hongkong, China, June 14 – 19.
Bracher Annina	DIMACS Center for Discrete Mathematics and Theoretical Computer Science, New Brunswick, USA, March 31 – April 3.
Moser Stefan	IEEE International Symposium on Information Theory, Hongkong, China, June 14 – 19.
Moser Stefan	National Chiao Tung University, Hsinchu, Taiwan, April 27 – 28.
Loeliger H.A.	Information Theory and Applications Workshop, San Diego, USA, January 29 – February 8.
Loeliger H.A.	IEEE International Symposium on Information Theory, Hongkong, China, June 14 – 19.
Jiun Hung Yu	IEEE International Symposium on Information Theory, Hongkong, China, June 14 – 19.
Sarah Neff	IEEE International Symposium on Information Theory, Hongkong, China, June 14 – 19.
Sarah Neff	ICASSP 40th IEEE International Conference on Acoustics, Speech and Signal Processing, Brisbane, Australia, April 19 – 24.
Hampus Malmberg	IEEE International Symposium on Information Theory, Hongkong, China, June 14 – 19.
Nour Zalmai	IEEE International Symposium on Information Theory, Hongkong, China, June 14 – 19.
Federico Wadehn	BIOSTEC 8th International Joint Conference on Biomedical Engineering Systems and Technologies, Lissabon, Portugal, January 12 – 15.
Federico Wadehn	EMBC 37th annual International Conference of the IEEE Engineering in Medicine and Biology, Milano, Italy, August 25 – 29.
Frederico Wadehn	Computing in Cardiology, Nice, France, September 8 – 9.

4.2 Invited Lectures and Seminars

26.2. – 12.3.2015	**Dr. Christian Schlegel,** Dalhous University Halifax, Novia Scotia, Canada 3 Lectures
11.05.2015	**Dr. Amir Bennatan**, Samsung, Israel "Soft-Decoding-Based Strategies for Relay and Interfence Channels: Analysis and Achievable Rates Using LDPC Codes"
13.05.2015	**Dr. Sergey Loyka**, University of Ottawa, Ottawa, Canada "A General Formula for Compound Channel Capacity"
22.05.2015	**Dr. Pascal Vontobel,** Chinese University of Hongkong, Hongkon "Factor Graph Transforms"
29.07.2015	**Dr. Tobias Koch,** Universidad Carlos III de Madrid, Leganés, Spain "On Shannons Lower Bound and Rényi's Information Dimension"
25.08.2015	**Dr. Igal Sason**, Technion, Israel Institute of Technology, Haifa, Israel "On the Renyi divergence, the joint range of relative entropies, and a channel coding theorem"
25.08.2015	**Dr. Michèle Wigger,** Telecom ParisTech, Paris, France "Constrained intra-cell and inter-cell cooperation in cellular networks"
29.09.2015	**Dr. Ronit Bustin,** Princeton University, New Jersey, USA "Gaussian Channels: Mutual Information-MMSE at Every SNR"

5. Service Activities

5.1 Conference Organization

Prof. Lapidoth	Co-Chair, 2016 International Zurich Seminar on Communications
Dr. Moser	Co-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
	Chair, IEEE Switzerland Chapter on Digital Communication Systems
	Member of the Executive Board of the IEEE Transactions on Information Theory