Conference Program

Compressed Sensing and its Applications

Matheon Workshop 2013

December 9-13, 2013

Technische Universität Berlin

Time	Monday	Tuesday	Wednesday	Thursday	Friday
08:00 – 08:45	Registration (from 07:30)	Registration	Registration	Registration	Registration
08:45 – 09:00	**Welcome Remarks**				
09:00 – 10:00	**V. Mehrmann**	**G. Sapiro**	**B. Hassibi**	**M. Vetterli**	**H. Bölcskei**
10:00 – 10:30	Coffee Break	Coffee Break	Coffee Break	Coffee Break	Coffee Break
10:30 – 11:05	R. Gribonval	R. Willett	H. Rauhut	R. Schneider	M. Rodrigues
11:05 – 11:40	P. Boufounos	V. Cevher	A. Hansen	S. Friedland	P. Jung
11:40 – 12:15	M. Davenport	C. Schütte	M. Fickus	M. Fornasier	P. Walk
12:15 – 14:00	Lunch Break	Lunch Break	Lunch Break	Lunch Break	**Final Remarks** (12:15 – 12:30)
14:00 – 15:00	**A. Pezeshki**	**Poster Session** & Coffee	**Excursion**	**R. Baraniuk**	
15:00 – 15:30	Coffee Break			Coffee Break	
15:30 – 16:05	D. Gross			D. Mixon	
16:05 – 16:40	C. Rozell			R. Ward	
16:40 – 17:15	W. Bajwa			F. Krahmer	
18:00 –			**Conference Dinner**		

Welcome

It is our great pleasure to welcome you at the Technische Universität Berlin to the MATHEON Workshop on “Compressed Sensing and its Applications”. This booklet has been put together to provide you with all relevant information on the workshop and to aid you during your stay in Berlin.

We would like to express our gratitude to all Plenary and Invited Speakers for accepting our invitation, as well as to all participants for visiting the Technische Universität Berlin to join this conference. We also gratefully acknowledge support by the Deutsche Forschungsgemeinschaft (DFG), the DFG Research Center MATHEON “Mathematics for key technologies” in Berlin, and the Technische Universität Berlin.

No conference would be possible without a team of dedicated volunteers, and we gratefully acknowledge the help of all members of the Applied Functional Analysis Group at the Technische Universität Berlin:

Martin Genzel
Mijail Guillemard
Anja Hedrich
Sandra Keiper
Anton Kolleck
Wang-Q Lim
Jackie Ma
Victoria Paternostro
Philipp Petersen
Friedrich Philipp
Rafael Reisenhofer
Martin Schäfer
Irena Stojanoska
Yizhi Sun

If you have any questions, please feel free to come to the registration desk, which will be open each day from 8:00AM until the end of the lectures/poster session, or contact anyone else from the team whose members are identifiable by a yellow name tag.

We now wish you an exciting conference, which we hope will bring you fruitful scientific exchange and many new contacts.

Holger Boche, Robert Calderbank, Gitta Kutyniok, and Jan Vybiral

Program for Matheon Workshop CSA2013

All talks will take place in Room H 3005.

<u>Monday, 9. 12.</u> *7:30-8:45* *Registration (Room H 3004)*
8:45-9:00 *Welcome remarks*

9:00-10:00 **Volker Mehrmann** (*Technische Universität Berlin, Germany*)
Reduced order modeling of parameter dependent nonlinear eigenvalue bifurcation problems
10:00-10:30 *Coffee break (Room H 3004)*
10:30-11:05 Rémi Gribonval *(Centre de Recherche INRIA Rennes, France)*
Fundamental performance limits of decoders in high-dimensional linear inverse problems
11:05-11:40 Petros Boufounos (*Mitsubishi Electric Research Laboratory, USA*)
On the representation and coding of signal distances
11:40-12:15 Mark Davenport (*Georgia Institute of Technology, USA*)
Compressive sensing in the analog world

12:15-14:00 *Lunch break*

14:00-15:00 **Ali Pezeshki** (*Colorado State University, USA*)
Compressed sensing and high-resolution image inversion
15:00-15:30 *Coffee break (Room H 3004)*
15:30-16:05 David Gross (*Universität Freiburg, Germany*)
A partial derandomization of PhaseLift using spherical designs
16:05-16:40 Chris Rozell (*Georgia Institute of Technology, USA*)
On the move: Dynamical systems for modeling, measurement and inference in compressed sensing
16:40-17:15 Waheed Bajwa *(Rutgers University, USA)*
Low-complexity subspace unmixing

<u>Tuesday, 10. 12.</u> *8:00-9:00* *Registration (Room H 3004)*

9:00 – 10:00 **Guillermo Sapiro** (*Duke University, USA*)
Learning to cluster and classify
10:00-10:30 *Coffee break (Room H 3004)*
10:30-11:05 Rebecca M. Willett (*Duke University, USA*)
Minimax optimal rates for photon-limited compressed sensing
11:05-11:40 Volkan Cevher (*EPFL, Switzerland*)
Composite self-concordant minimization
11:40-12:15 Christof Schütte (*Freie Universität Berlin & Zuse-Institut Berlin (ZIB), Germany*)
Sparsity in molecular dynamics

12:15-14:00 *Lunch break*
14:00-17:15 **Poster Session & Coffee** *(Atrium of the main building)*

<u>Wednesday, 11. 12.</u> *8:00-9:00* *Registration (Room H 3004)*

9:00-10:00 **Babak Hassibi** (*California Institute of Technology, USA*)
Recovering structured signals from noisy measurements: Where least-squares meets compressed sensing

10:00-10:30 *Coffee break (Room H 3004)*
10:30-11:05 Holger Rauhut (*RWTH Aachen, Germany*)
Interpolation via weighted l1-minimization
11:05-11:40 Anders Hansen (*University of Cambridge, UK*)
Compressed sensing in the real world - The need for a new theory
11:40-12:15 Matthew Fickus (*AFIT, USA*)
Equiangular tight frames and the restricted isometry property

12:15-14:00 *Lunch break*

14:00-18:00 **Excursion**
18:00 **Conference Dinner**

Thursday, 12. 12. *8:00-9:00 Registration (Room H 3004)*

9:00-10:00 **Martin Vetterli** (*EPFL, Switzerland*)
Inverse problems regularized by sparsity
10:00-10:30 *Coffee break (Room H 3004)*
10:30-11:05 Reinhold Schneider (*Technische Universität Berlin, Germany*)
Numerical methods for low rank recovery of hierarchical tensors
11:05-11:40 Shmuel Friedland (*University of Illinois at Chicago, USA*)
Compressive sensing of sparse tensors
11:40-12:15 Massimo Fornasier *(Technische Universität München, Germany)*
Quasi-linear compressed sensing and applications in asteroseismology

12:15-14:00 *Lunch break*

14:00-15:00 **Richard Baraniuk** (*Rice University, USA*)
Video compressive sensing
15:00-15:30 *Coffee break (Room H 3004)*
15:30-16:05 Dustin Mixon (*AFIT, USA*)
A new approach to derandomize compressed sensing matrices
16:05-16:40 Rachel Ward *(University of Texas at Austin, USA)*
Stochastic gradient descent with importance sampling
16:40-17:15 Felix Krahmer *(Universität Göttingen, Germany)*
Dimension reduction techniques for efficient subspace approximation

Friday, 13. 12. *8:00-9:00 Registration (Room H 3004)*

9:00-10:00 **Helmut Bölcskei** (*ETH Zürich, Switzerland*)
Signal recovery, uncertainty relations, and Rényi information dimension
10:00-10:30 *Coffee break (Room H 3004)*
10:30-11:05 Miguel Rodrigues (*University College London, UK*)
Fundamental limits on the performance of compressive classification: A characterization inspired by dualities between classification and wireless communications problems
11:05-11:40 Peter Jung (*Technische Universität Berlin, Germany*)
Low-complexity model uncertainties in compressed sensing with application to sporadic communication
11:40-12:15 Philipp Walk (*Technische Universität München, Germany*)
Stable embedding of sparse convolutions
12:15-12:30 *Closing remarks*

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Monday Plenary Talks

Reduced order modeling of parameter dependent nonlinear eigenvalue bifurcation problems

Volker Mehrmann

Technische Universität Berlin, Germany

09:00–10:00

We present results and challenges from an industrial project on the reduction of squealing noise in disk brakes. The model is given by a large scale ordinary differential equation (arising from FEM modeling) that is parameter dependent (e.g. the rotation frequency of the disk) and the goal is to obtain a small scale reduced model which is valid in a large parameter range that can be used for real time optimization and control.

We discuss the construction of appropriate projection methods based on an oversampling over the frequency range and appropriate compression methods based on singular value decompositions.

Joint work with C. Schröder and S. Quraishi.

Compressed sensing and high-resolution image inversion

Ali Pezeshki

Colorado State University, USA

14:00–15:00

Broadly speaking there are two classical principles for inverting the kinds of images that are measured in optics, electromagnetics and acoustics. The first principle is one of matched filtering, wherein a sequence of rank-one subspaces, or one-dimensional test images, is matched to the measured image by filtering, correlating, or phasing in frequency, wavenumber, doppler, and/or delay. The second principle is one of parameter estimation in a separable linear model, wherein a sparse modal representation for the field is posited and estimates of linear parameters (complex amplitudes of modes) and nonlinear mode parameters (frequency, wavenumber, delay, and/or doppler) are extracted, usually based on maximum likelihood, or some variation on linear prediction. An important limitation of the classical principles is that any subsampling of the measured image has consequences for resolution (or bias) and for variability (or variance). There is a comprehensive literature on bounding the performance of such methods.

Compressed sensing theory stands in contrast to the classical principles. It states that complex baseband data may be compressed before processing, when it is known *a priori* that the field to be imaged is sparse in a known dictionary, and it suggests that subsampling has manageable consequences for image inversion. Moreover, the compression step in compressed sensing typically employs randomly drawn linear combinations, which stand in stark contrast to the linearly phased combinations that are used to form narrow bands in time series analysis and focused beams in space series analysis.

But how does the performance of compressed sensing compare with that of classical and modern methods of modal analysis, such as matched filters, generalized sidelobe cancelers, MUSIC, and exact likelihood approximations? This is the general question that we discuss in this talk. More specifically, we will discuss recent analytical and experimental results which shed light on the following fundamental questions:

1. Sensitivity to model mismatch: What is the sensitivity of compressed sensing to mismatch between the physical model that generated the data and the mathematical model that is assumed in the inversion algorithm? Can these sensitivities be mitigated by over resolving the mathematical model to ensure that mathematical modes are close to physical modes? For inversion problems where mismatch turns sparse problems into incompressible problems, can the imaging system or the inversion algorithm be modified to restore compressibility?

2. Loss of Fisher Information: What is the impact of compressive sampling on the Fisher information matrix, Cramer-Rao bound (CRB), and Kullback-Leibler divergence for estimating nonlinear parameters? How well does a compressively recorded version of a space-time image preserve information about the field of scatterers to be estimated?

3. Threshold effects and performance breakdowns: What is the impact of compressive sampling on SNR thresholds at which mean-squared error (MSE) in estimating parameters deviate sharply from the CRB? What is the impact of compressive sampling on the probability of a swap of signal and noise subspaces in the data? Can these threshold effects be predicted analytically to

guide or design compression?

4. Cross-validation: In the absence of information about noise variance and model mismatch, how can we evaluate whether or not an extracted solution from compressive sensing is acceptable? Is there a cross-validation procedure that will tell when a compressed sensing solution is acceptable?

Monday Invited Talks

Morning Session

10:30–11:05 **Fundamental performance limits of decoders in high-dimensional linear inverse problems**

Rémi Gribonval, Centre de Recherche INRIA Rennes - Bretagne Atlantique, France

The primary challenge in linear inverse problems is to design stable and robust "decoders" to reconstruct high-dimensional vectors from a low-dimensional observation through a linear operator. Sparsity, low-rank, and related assumptions are typically exploited to design decoders which performance is then bounded based on some measure of deviation from the idealized model, typically using a norm.

This talk focuses on characterizing the fundamental performance limits that can be expected from an ideal decoder given a general model, i.e., a general subset of "simple" vectors.

First, we extend the so-called notion of instance optimality of a decoder to settings where one only wishes to reconstruct some part of the original high dimensional vector from a low-dimensional observation. This covers practical settings such as medical imaging of a region of interest, or audio source separation when one is only interested in estimating the contribution of a specific instrument to a musical recording. We define instance optimality relatively to a model much beyond the traditional framework of sparse recovery, and characterize the existence of an instance optimal decoder in terms of joint properties of the model and the considered linear operator. Noiseless and noise-robust settings are both considered. We show somewhat surprisingly that the existence of *noise-aware* instance optimal decoders for all noise levels implies the existence of a *noise-blind* decoder.

A consequence of our results is that for models that are rich enough to contain an orthonormal basis, the existence of an ℓ_2/ℓ_2 instance optimal decoder is only possible when the linear operator is not substantially dimension-reducing.

This covers well-known cases (sparse vectors, low-rank matrices) as well as a number of seemingly new situations (structured sparsity, sparse inverse covariance matrices ...). After discussing instance optimality with various pairs of norms, we exhibit an operator-dependent norm which, under a model-specific generalization of the Restricted Isometry Property (RIP), always yields a feasible instance optimality and implies instance optimality with certain familiar atomic norms such as the ℓ_1 norm.

We conclude by discussing to what extent the generalized RIP is necessary, and draw connections with non-uniform results with Gaussian matrices and atomic norms.

This is joint work with Anthony Bourrier, Mike E. Davies, Tome Peleg, and Patrick Perez.

11:05–11:40 **On the representation and coding of signal distances**
Petros Boufounos, Mitsubishi Electric Research Laboratory, USA

Traditional signal representation and coding theory is focused on how to most efficiently represent and encode a signal with the goal of preserving it as best as possible. However, very often, the processing only concerns specific information in the signal and does not require conserving the signal itself. In this talk we examine the problem of representing signals such that some function of their distance is preserved. For that goal, we consider randomized embeddings as a representation mechanism and provide a framework to design them and analyze their performance. Our work generalizes previously developed universal embeddings, already proven quite successful in practice.

This is joint work with Shantanu Rane.

11:40–12:15 **Compressive sensing in the analog world**
Mark Davenport, Georgia Institute of Technology, USA

While compressive sensing is often motivated as an alternative to Nyquist-rate sampling, there remains a gap between the discrete, finite-dimensional compressive sensing framework and the problem of acquiring a continuous-time signal. In this talk I will discuss one approach to bridging this gap by exploiting Discrete Prolate Spheroidal Sequences (DPSS's), a collection of functions that trace back to the seminal work by Slepian, Landau, and Pollack on the effects of time-limiting and bandlimiting operations. DPSS's form a highly efficient basis for sampled bandlimited functions; by modulating and merging DPSS bases, we obtain a dictionary that offers high-quality sparse approximations for most sampled multiband signals. This multiband modulated DPSS dictionary can be readily exploited by standard sparse recovery algorithms, but unfortunately, this dictionary is highly coherent, and the standard theoretical guarantees do not apply. This difficulty motivates a new variant of the iterative recovery algorithm CoSaMP for this setting which is more "signal-focused";

that is, it is oriented around recovering the signal rather than its dictionary coefficients. While important theoretical questions regarding this algorithm remain open, we will see that the algorithm often empirically exhibits superior performance to traditional recovery algorithms.

Afternoon Session

15:30–16:05 **A partial derandomization of phaselift using spherical designs**
David Gross, Universität Freiburg, Germany

The problem of retrieving phase information from amplitude measurements alone has appeared in many scientific disciplines over the last century. PhaseLift is a recently introduced algorithm for phase recovery that is numerically stable and comes with rigorous performance guarantees. PhaseLift is optimal in the sense that the number of amplitude measurements required for phase reconstruction scales linearly with the dimension of the signal. However, it specifically demands sub-Gaussian random measurement vectors and the question arises whether more highly structured measurement ensembles are already sufficient. Here we present a partial derandomization of PhaseLift that only requires sampling from certain finite vector configurations, called t-designs. Such configurations have been studied in algebraic combinatorics, coding theory, and quantum information. Beyond the specific case of PhaseLift, this work highlights the utility of spherical designs for the derandomization of data recovery schemes. Joint work with Richard Kueng and Felix Krahmer.

16:05–16:40 **On the move: Dynamical systems for modeling, measurement and inference in compressed sensing**
Chris Rozell, Georgia Institute of Technology, USA

Compressed sensing (CS) systems involve three major components: a low-dimensional model for the data of interest, a measurement process, and a recovery algorithm. In this talk I will give an overview of some of our recent results in CS where modeling, measurement and inference intersects with the field of dynamical systems. Time permitting, I will attempt to address four main questions. Can the principles of Kalman filtering be applied for effective dynamic filtering of time-varying sparse signals? Can signal recovery be performed when the measurement system itself is a dynamical system? Can dynamical systems give us insight into ultra-efficient signal recovery systems? Can measurement operators preserve information about attractors of dynamical systems?

16:40–17:15 **Low-complexity subspace unmixing**
Waheed U. Bajwa, Rutgers University, USA

Classical literature in detection, estimation, classification,dimensionality reduction, etc., often assumes a subspace model, in which it is argued that signals of interest lie on or near a low- dimensional subspace of a higher-dimensional Hilbert space. Many of these existing results however deal with a small number of subspaces (say, N) relative to the dimension of the Hilbert space (say, D). On the other hand, proliferation of cheap sensors and low-cost semiconductor devices in the modern world means we often find ourselves dealing with a significantly larger number of subspaces relative to the extrinsic dimension. While many of the classical subspace-based results do not generalize in such "D smaller than N" settings, it is possible to leverage the classical subspace-based computational machinery for information processing as long as only a small number of subspaces (say, $n \ll N$) become "active" at any given instance and the set of active subspaces is known. One of the fundamental challenges for information processing in the D smaller than N setting could then be described as the recovery of the set of active subspace from D-dimensional observations, which we term as "subspace unmixing". In this talk, we formalize the problem of subspace unmixing, discuss its connections with and applications to compressed sensing, fusion frames, source separation, multivariate regression, etc., and propose and analyze a low-complexity algorithm for subspace unmixing.

Tuesday Plenary Talk

Learning to cluster and classify

Guillermo Sapiro

Duke University, USA

09:00–10:00

A low-rank transformation learning framework for subspace clustering and classifcation is here proposed. Many high-dimensional data, such as face images and motion sequences, approximately lie in a union of low-dimensional subspaces. The corresponding subspace clustering problem has been extensively studied in the literature to partition such high-dimensional data into clusters corresponding to their underlying low-dimensional subspaces. However, low-dimensional intrinsic structures are often violated for real-world observations, as they can be corrupted by errors or deviate from ideal models. We propose to address this by learning a linear transformation on subspaces using matrix rank, via its convex surrogate nuclear norm, as the optimization criteria. The learned linear transformation restores a low-rank structure for data from the same subspace, and, at the same time, forces a high-rank structure for data from dierent subspaces. In this way, we reduce variations within the subspaces, and increase separation between the subspaces for a more robust subspace clustering. This proposed learned robust subspace clustering framework significantly enhances the performance of existing subspace clustering methods. Basic theoretical results here presented help to further support the underlying framework. To exploit the low-rank structures of the transformed subspaces, we further introduce a subspace clustering technique, called Robust Sparse Subspace Clustering, which eciently combines robust PCA with sparse modeling. When class labels are present at the training stage, we show this low-rank transformation framework also significantly enhances classification performance. Extensive experiments using public datasets are presented, showing that the proposed approach significantly outperforms state-of-the-art methods for subspace clustering and classification.

This is joint work with Qing Qiu.

Tuesday Invited Talks

Morning Session

10:30–11:05 **Minimax optimal rates for photon-limited compressed sensing**
Rebecca M. Willett, Duke University, USA

In this talk, I will describe new performance bounds for compressed sensing (CS) in photon-limited imaging systems. Most CS theory is restricted to idealized settings where the noise is i.i.d. and does not account for the physical constraints of photon-limited imaging systems, including signal-dependent noise as well as positivity constraints. Prior results provide upper bounds for the performance of compressed sensing under Poisson noise. We now provide minimax lower bounds for this problem which reflect the fundamental limitations of CS in low-light settings. This is joint work with Xin Jiang and Garvesh Raskutti.

11:05–11:40 **Composite self-concordant minimization**
Volkan Cevher, EPFL, Switzerland

We propose a variable metric framework for minimizing the sum of a self-concordant function and a possibly non-smooth convex function endowed with a computable proximal operator. We theoretically establish the convergence of our framework without relying on the usual Lipschitz gradient assumption on the smooth part. An important highlight of our work is a new set of analytic step-size selection and correction procedures based on the structure of the problem. We describe concrete algorithmic instances of our framework for several interesting large-scale applications and demonstrate them numerically on both synthetic and real data.

11:40–12:15 **Sparsity in molecular dynamics**
Christof Schütte, Freie Universität Berlin & Zuse-Institut Berlin (ZIB), Germany

Molecular dynamics (MD) simulations allow for analysis and understanding of this dynamical behavior of molecular systems. However realistic simulations on timescales beyond milliseconds and sizes beyond 100.000s of atoms are still infeasible even on the most powerful computers, which renders the MD-based analysis of many processes related to biological function impossible. However, the literature contains many observations of sparsity in molecular dynamics although it is almost never used to speed-up simulations. The talk will review some of these insights and will outline related mathematical questions and possible ways to address them.

Afternoon Session

14:00–17:15 **Poster Session**
The poster session will take place in the atrium of the TU main building (Lichthof).

1. Angierski, Andre (*Universität Rostock)*

   Details on the CRB for FRI signals

2. Augustin, Sven (*Technische Universität Berlin)*

   Compressive THz - imaging

3. Ayaz, Ulas (*Universität Bonn)*

   Sparse recovery with fusion frames

4. Bartels, Andreas (*Universität Bremen)*

   An application of compressed sensing in imaging mass spectrometry

5. Bilen, Cagdas (*Institute for research in computer science and random systems)*

   Blind sensor calibration in sparse recovery using convex optimization

6. Bubacarr, Bah (*EPFL)*

   Model-based sketching and recovery with expanders

7. Candeia, Gurjao Edmar (*Federal University of Campina Grande)*

   Architectures for analog-to-information converters

8. Dankova, Marie (*Brno University of Technology)*

   Compressed sensing of perfusion MRI

9. Dekorsy, Armin (*Universität Bremen)*

   Compressed sensing enabled detection in wireless communication

10. Feng, Joe-Mei (*Universität Göttingen)*

    An RIP-based approach to $\Sigma\Delta$-quantization for compressed sensing

11. Fry, Alexandra (*University of Alabama at Birmingham)*

    Using a tensor method for high-dimensional multilinear systems to map genomic interactions

12. James, David (*Universität Göttingen)*

    Sparse recovery with random convolutions

13. Joergensen, Jakob Sauer (*Technical University Denmark)*

    t.b.a.

14. Jones, Alexander Daniel (*University of Cambridge)*

Asymptotic incoherence and its implications for compressed sensing for inverse problems

15. Kabanava, Maryia (*RWTH Universität Aachen)*

Recovery of cosparse signals with Gaussian measurements

16. Kazimierczuk, Krzysztof (*University of Warsaw)*

Studying temperature-dependent molecular changes with CS-NMR

17. Király, Franz J. (*Technische Universität Berlin)*

Algebraic compressed sensing

18. Kruschel, Christian (*Technische Universität Braunschweig)*

Geometrical insights to sparse recovery

19. Li, Kezhi (*Royal Institute of Technology)*

Low rank matrix recovery using Toeplitz matrices

20. Lisowska, Agnieszka (*University of Silesia Katowice)*

Multismoothlets

21. Liu, Yipeng (*Katholieke Universiteit Leuven)*

Robust sparse signal recovery for compressed sensing with sampling and representation uncertainties

22. Lu, Yun (*Technische Universität Dresden)*

Improved compressed sensing by noise-mitigated least squares

23. Lucka, Felix (*Universität Münster)*

Sparse recovery conditions and realistic forward modeling in EEG/MEG source reconstruction

24. Mayer, Sebastian (*Universität Bonn)*

PAC-learning and random dimensionality reduction

25. Mota, Joao (*University College London)*

Distributed compressed sensing algorithms: completing the puzzle

26. Mousavi, Ali (*Rice University)*

Parameterless optimal approximate message passing

27. Navasca, Carmeliza (*University of Alabama at Birmingham)*

Low rank tensor completion via alternating minimization

28. Peter, Steffen (*Technische Universität München)*

    Damping noise-folding and enhanced support recovery in compressed sensing

29. Philipp, Friedrich (*Technische Universität Berlin)*

    Phase retrieval with 4d-4 measurements

30. Poloni, Federico (*University of Pisa)*

    Permuted graph bases for solving large and sparse matrix equations

31. Poon, Clarice (*University of Cambridge)*

    On the use of frames and total variation in compressed sensing

32. Quraishi, Sarosh Mumtaz (*Technische Universität Berlin)*

    Dictionary based approach for PDE discretizations

33. Reisenhofer, Rafael (*Technische Universität Berlin)*

    ShearLab 3D - faithful digital shearlet transform with compactly supported shearlets

34. Sanders, Jacob (*Harvard University)*

    Compressed sensing for recovery of sparse matrices: applications to computational chemistry

35. Sauer, Joergensen Jakob (*Technical University of Denmark)*

    Empirical phase transitions in computed tomography

36. Sauer, Tomas (*Universität Passau)*

    SMAP - geometrical object with minimal support

37. Scheunert, Christian (*Technische Universität Dresden)*

    Improved compressed sensing by noise mitigated least squares

38. Schnass, Karin (*University of Sassari)*

    Learning non-tight dictionaries

39. Soltani, Sara (*Technical University of Denmark)*

    A tomographic reconstruction method using learned dictionaries

40. Sparrer, Susanne (*Universität Ulm)*

    Discrete compressed sensing algorithms

41. Stojanac, Zeljka (*Universität Bonn)*

    RIP for tensors

42. Stojanoska, Irena (*Technische Universität Berlin*)

    Geometric sparsity and structured compressed sensing

43. Urbanczyk, Mateusz (*University of Warsaw*)

    A combined sparse sampling of time-gradient domain for NMR diffusometry and relaxometry

44. Valley, George C. (*The Aerospace Corporation*)

    Compressive sensing RF signals with an optical wideband converter

45. Wang, Hui (*Katholieke Universiteit Leuven*)

    A SVD-based matrix pencil method for sparse reconstruction of EEG signals

46. Xu, Hantao (*Katholieke Universiteit Leuven*)

    Compressive sensing application on direction finding array receiver

47. Zahra, Noore (*Sharda University*)

    Compressive sensing in analysis of brain tumor

48. Zhukov, Nikolay (*University of Warsaw*)

    Extending NMR signal with CS algorithms

49. Zörlein, Henning (*Universität Ulm*)

    BASC based coherence optimization applied to compressed sensing

Wednesday Plenary Talk

Recovering structured signals from noisy measurements: where least-squares meets compressed sensing

Babak Hassibi

California Institute of Technology, USA

14:00–15:00

We consider the problem of recovering a structured signal (sparse, low-rank, block-sparse, etc.) from noisy compressed measurements. A general algorithm for such problems, commonly referred to as generalized LASSO, attempts to solve this problem by minimizing a least-squares cost with an added "structure-inducing" regularization term (ℓ_1 norm, nuclear norm, mixed ℓ_2/ℓ_1 norm, etc.). When the measurement matrix consists of iid Gaussian entries we provide a full performance analysis of the generalized LASSO algorithm and compute, in closed form, the normalized square error of the reconstructed signal. We will highlight some of the mathematical vignettes necessary for the analysis, including Gordon's comparison lemma for Gaussian processes, and projections onto the sub-differential cone of the structure-inducing function. We will also make connections to noiseless compressed sensing and the proximity operator in denoising, and will emphasize the central role of the "statistical dimension", i.e., the minimum number of measurements needed to reconstruct a structured signal by minimizing an appropriate convex function. We provide extensive numerical examples to validate the results and mention several open problems.

Wednesday Invited Talks

Morning Session

10:30–11:05 **Interpolation via weighted ℓ_1-minimization**
Holger Rauhut, RWTH Aachen, Germany

Functions of interest are often smooth and sparse in some sense, and both priors should be taken into account when interpolating sampled data. Classical linear interpolation are effective under strong regularity assumptions, but cannot incorporate nonlinear sparsity structure. At the same time, nonlinear methods such as ℓ_1-minimization can reconstruct sparse functions from very few samples, but do not necessarily encourage smoothness. It turns out that weighted ℓ_1-minimization effectively merges the two approaches, promoting both sparsity and smoothness in reconstruction. In this talk, I will present theoretical results on reconstruction error estimates for weighted ℓ_1-minimization which build on concepts from compressive sensing. The theory is underlined by numerical experiments.

11:05–11:40 **Compressed sensing in the real world - The need for a new theory**
Anders Hansen, University of Cambridge, UK

Compressed sensing is based on the three pillars: sparsity, incoherence and uniform random subsampling. In addition, the concepts of uniform recovery and the Restricted Isometry Property (RIP) have had a great impact. Intriguingly, in an overwhelming number of inverse problems where compressed sensing is used or can be used (such as MRI, X-ray tomography, Electron microscopy, Reflection seismology etc.) these pillars are absent. Moreover, easy numerical tests reveal that with the successful sampling strategies used in practice one does not observe uniform recovery nor the RIP. In particular, none of the existing theory can explain the success of compressed sensing in a vast area where it is used. In this talk we will demonstrate how real world problems are not sparse, yet asymptotically sparse, coherent, yet asymptotically incoherent, and moreover, that uniform random subsampling yields highly suboptimal results. In addition, we will present easy arguments explaining why uniform recovery and the RIP is not observed in practice. Finally, we will introduce a new theory that aligns with the actual implementation of compressed sensing that is used in applications. This theory is based on asymptotic sparsity, asymptotic incoherence and random sampling with different densities. This theory supports two intriguing phenomena observed in reality: 1. the success of compressed sensing is resolution dependent, 2. the optimal sampling strategy is signal structure dependent. The last point opens up for a whole new area of research, namely the quest for the optimal sampling strategies.

11:40–12:15 **Equiangular tight frames and the restricted isometry property**
Matthew Fickus, AFIT, USA

An equiangular tight frame (ETF) is a type of optimal packing of a given number of lines in a Euclidean space of a given dimension. Such frames have minimal coherence, making them attractive for compressed sensing (CS) applications. However, like all known deterministic constructions of matrices, ETFs suffer from the "square-root bottleneck," meaning the degree to which they satisfy CS's restricted isometry property (RIP) pales in comparison to random matrices. For most deterministic constructions, it is unknown whether this bottleneck is simply a consequence of poor proof techniques or, more seriously, a flaw in the matrix design itself. We focus on this issue in the special case of ETFs. In particular, we discuss the degree to which the recently-introduced Steiner and Kirkman ETFs satisfy the RIP. We further discuss how a popular family of ETFs, namely harmonic ETFs arising from McFarland difference sets, are particular examples of Kirkman ETFs. Overall, we find that many families of ETFs are shockingly bad when it comes to RIP, being provably incapable of exceeding the square-root bottleneck.

Thursday Plenary Talks

Inverse problems regularized by sparsity

Martin Vetterli

EPFL, Switzerland

09:00–10:00

Sparsity as a modeling principle has been part of signal processing for a long time, for example, parametric methods are sparse models. Sparsity plays a key role in non-linear approximation methods, in particular using wavelets and related constructions. And recently, compressed sensing and finite rate of innovation sampling have shown how to sample sparse signals close to their sparsity levels.

In this talk, we first recall that signal processing lives on the edge of continuous- and discrete-time/space processing. That duality of the continuum versus the discrete is also inherent in inverse problems. We then review how sparsity can be used in solving inverse problems. This can be done when the setting is naturally sparse, e.g. in source localization, or for solutions that have low-dimensionality in some basis. After an overview of essential techniques for sparse regularization, we present several examples where concrete, real life inverse problems are solved using sparsity ideas.

First, we answer the question "can one hear the shape of a room", a classic inverse problem from acoustics. We show a positive answer, and a constructive algorithm to recover room shape from only a few room impulse responses.

Second, we address the problem of source localization in a graph. Assume a disease or a rumor spreading on a social graph, can one find the source efficiently with a small set of observers? A constructive and efficient algorithm is described, together with several practical scenarios.

Third, we consider the question of sensor placement for monitoring and inversion of diffusion processes. We present a solution for monitoring temperature using low dimensional modeling and placing a small set of sensors.

The ideas of sparse, regularized inversion are finally applied to the problem of trying to recover the amount of nuclear release from the Fukushima nuclear accident. We show that using a transport model and the very limited available measurements, we are able to correctly recover Xenon emission, while the Cesium release remains a challenge.

Video compressive sensing

Richard Baraniuk

Rice University, USA

14:00–15:00

Sensing and imaging systems are under increasing pressure to accommodate ever larger and higher-dimensional data sets; ever faster capture, sampling, and processing rates; ever lower power consumption; communication over ever more difficult channels; and radically new sensing modalities. Since its discovery in 2004, compressive sensing (CS) has stimulated a re-thinking of sensor and signal processing system design. In CS, analog signals are digitized and processed not via uniform sampling but via measurements using more general, even random, test functions. In contrast with conventional wisdom, the new theory asserts that one can combine "sub-Nyquist-rate sampling" with large-scale optimization for efficient and accurate signal acquisition when the signal has a sparse structure. In this talk, we will review the progress in field over the last 8 years, with a special emphasis on the pros and cons of the technique and on sensing ephemeral signals such as videos.

Thursday Invited Talks

Morning Session

10:30–11:05 **Numerical methods for low rank recovery of hierarchical tensors**
Reinhold Schneider, Technische Universität Berlin, Germany

In the present talk we want to recover low-rank tensors in recenthierarchical tensor formats from a small number of measurements. For measurements which are simply point evaluations, it will be refer to as *tensor completion* or *tensor interpolation*. the introduction of hierarchical tensor representations (HT and TT), see e.g. the recent monograph “Tensor spaces and numerical tensor calculus” by W. Hackbusch, tensor product approximation has witnessed substantial progress in the past few years. This novel tensor representation admits a well defined rank vector **r**, a quasi-optimal approximation tool, HOSVD, and analytic geometric structures. Therefore it offers a powerful tool for circumventing the curse of dimensionality and, therefore, to scope with high dimensional data. We pursue on searching for a tensor in our model class of hierarchical tensors of desired multi-rank **r**, which fits best to the given data. For this purpose we will follow strategies developed for matrix completion, namely

1. Hard Thresholding
2. Riemannian optimization
3. Soft Thresholding.

11:05–11:40 **Compressive sensing of sparse tensors**
Shmuel Friedland, University of Illinois at Chicago, USA

Compressive sensing (CS) has triggered enormous research activity since its first appearance. CS exploits the signal's sparseness or compressibility in a particular domain and integrates data compression and acquisition, thus allowing exact reconstruction through relatively few non-adaptive linear measurements. While conventional CS theory relies on data representation in the form of vectors, many data types in various applications such as color imaging, video sequences, and multi-sensor networks, are intrinsically represented by higher-order tensors. Application of CS to higher-order data representation is typically performed by conversion of the data to very long vectors that must be measured using very large sampling matrices, thus imposing a huge computational and memory burden. In this talk we introduce Tensor Compressive Sensing (TCS) – a unified framework forcompressive sensing of higher-order sparse tensors. TCS offers an efficient means for representation of multidimensional data by providing simultaneous acquisition and compression from all tensor modes. In addition, we propound two reconstruction procedures, a serial method (TCS-S) and a parallelizable method (TCS-P). We then compare the performance of the proposed method with Kronecker compressive sensing (KCS) and multi-way compressive sensing (MWCS). We demonstrate experimentally that TCS outperforms KCS and MWCS in terms of both accuracy and speed. The talk is based on a joint paper with Qun Li and Dan Schonfeld http://arxiv.org/abs/1305.5777.

11:40–12:15 **Quasi-linear compressed sensing and applications in asteroseismology**
Massimo Fornasier, Technische Universität München, Germany

Inspired by significant real-life applications, in particular, sparse phase retrieval and sparse pulsation frequency detection in Asteroseismology, we investigate a general framework for compressed sensing, where the measurements are quasi-linear. We formulate natural generalizations of the well-known Restricted Isometry Property (RIP) towards nonlinear measurements, which allow us to prove both unique identifiability of sparse signals as well as the convergence of recovery algorithms to compute them efficiently.

Afternoon Session

15:30–16:05 **A new approach to derandomize compressed sensing matrices**
Dustin Mixon, AFIT, USA

The restricted isometry property (RIP) is a compressed sensing matrix specification which leads to performance guarantees for a wide variety of sparse signal reconstruction algorithms. For the sake of quality sensing standards, practitioners desire deterministic sensing matrices, but the best known deterministic RIP matrices are vastly inferior to those constructed using random processes. This talk presents a new way to pursue good deterministic RIP matrices. Taking inspiration from certain work in number theory and discrepancy theory, we consider particular notions of pseudorandomness in a sequence, and we populate a sensing matrix with consecutive members of such a sequence, starting at a random member of the sequence. To demonstrate RIP, we chiefly leverage the sequence's pseudorandomness so that very little randomness is needed to seed the construction. We suspect that a more refined notion of pseudorandomness will completely derandomize this construction.

16:05–16:40 **Stochastic gradient descent with importance sampling**
Rachel Ward, University of Texas at Austin, USA

In this talk we provide improved estimates on the exponential convergence rate of stochastic gradient descent (SG) for smooth strongly convex objectives, in the regime where all stochastic estimates share an optimum and so such an exponential rate is possible. Next, we show that by incorporating importance sampling – perturbing the uniform row selection rule in the direction of sampling estimates proportionally to the Lipschitz constant of their gradients – the convergence rate of SG can be improved dramatically from depending on the average squared condition number to depending on the average (unsquared) condition number of the system. Finally, we recast the randomized Kaczmarz algorithm for solving linear systems as an instance of preconditioned stochastic gradient descent, allowing us to prove its exponential convergence to the solution of a weighted least squares problem.

This is joint work with Deanna Needell and Nati Srebro.

16:40–17:15 **Dimension reduction techniques for efficient subspace approximation**
Felix Krahmer, Universität Göttingen, Germany

The goal of the subspace approximation problem is to find a linear subspace of prescribed dimension that approximates a point set in a given norm. The case of the

Euclidean norm gives rise to the least squares problem, for which efficient solution algorithms exist. In certain applications, however, the use of ℓ_p-norms, $p > 2$, is preferred. In this talk we propose an efficient algorithm for solving this problem, which is based on a least squares based dimension reduction. This is joint work with Mark Iwen.

Friday Plenary Talk

Signal recovery, uncertainty relations, and Rényi information dimension

Helmut Bölcskei

ETH Zürich, Switzerland

09:00–10:00

The aim of this talk is to develop a unified framework for understanding the fundamental limits of a wide range of signal reconstruction problems such as image inpainting, super-resolution, signal separation, denoising, and recovery of signals that are impaired by, e.g., clipping, impulse noise, or narrowband interference. We first consider the case of deterministic signals and establish the fundamental role played by uncertainty relations. An information-theoretic formulation allowing for random signals leads us to an almost lossless analog signal separation problem and reveals Rényi information dimension and Minkowski dimension as the foundational elements of the theory. As a byproduct, we discover a new technique for showing that the intersection of generic subspaces with subsets of sufficiently small Minkowski dimension is empty. This result can be viewed as a measure-theoretic version of the null-space property widely used in compressed sensing theory.

Friday Invited Talks

Morning Session

10:30–11:05 **Fundamental limits on the performance of compressive classification: a characterization inspired by dualities between classification and wireless communications problems**
Miguel R. D. Rodrigues, University College London, UK

Compressive sensing is an emerging paradigm that offers the means to simultaneously sense and compress a signal with virtually no loss of information. The sensing process is based on the projection of the signal of interest onto a set of vectors, which are typically constituted randomly, and the recovery process is based on the resolution of an inverse problem. The result that has captured the imagination of the information processing community is that it is possible to perfectly reconstruct a n-dimensional s-sparse signal with overwhelming probability with only $O(s\log(n/s))$ linear random measurements or projections using tractable recovery algorithms.

The focus of compressive sensing has been primarily on exact or near-exact signal reconstruction from the set of linear measurements. However, it is also natural to leverage the paradigm to perform other relevant information processing tasks, such as detection, classification and estimation of certain parameters.

This talk focus on the characterization of fundamental performance limits associated with compressive classification systems, where the objective is to discriminate high-dimensional Gaussian signals from noisy compressive measurements. By leveraging the syntactic equivalence between a compressive classification problem and the multiple-antenna wireless communications problem, we argue that it is possible to use tools from information and communications theory to construct performance characterizations that encapsulate as a function of the system parameters not only standard phase transitions but also other more refined notions borrowed from the wireless communications domain, including: i) adiversity gainthat determines how the probability of error decays asymptotically; and ii) adiscrimination gainthat determines the number of classes that can be discriminated with low probability of error asymptotically.

In particular, we prove inner and outer bounds on the number of classes that canbe discriminated with low probability of error as the signal dimensionality goes to infinity, as a function of the system parameters. We also prove inner and outer bounds on a fundamental relationship between the discrimination gain and the diversity gain – the so-called diversity-discrimination tradeoff – as a function of the system parameters. In addition, we also imbue such performance characterizations with considerable geometrical insight, e.g. it is revealed that the “easies” classes to discriminate correspond to subspaces drawn from an appropriate Grassmann manifold – an observation with implications for dictionary learning. The essence of the results is also illustrated via practical face recognition problems.

11:05–11:40 **Low-complexity model uncertainties in compressed sensing with application to sporadic communication**
Peter Jung, Technische Universität Berlin, Germany

Noncoherent compressed reception of information is a promising approach to cope with several future challenges for sporadic communication where short messages have to be communicated in an unsynchronized manner over unknown, but compressible, dispersive channels. For example, new network technologies like machine-type communication and new random access strategies are proposed under the vision of the ”internet of things”. To enable such new communication concepts efficiently, it is therefore necessary to investigate blind sampling strategies which explicitly account for the low-dimensional structure of the signals.

Since the compressed sensing paradigm provides a substantial reduction in sampling and storage complexity it is therefore also an advisable strategy for noncoherent information retrieval. However, in this and many related application the conventional linear estimation model is a quite strong assumption since here the compressible signals of interest are not accessible in the usual way. Instead they have to be estimated from sampling data taken solely on the output of an additional linear system which is itself unknown during measurement but often compressible. Thus, in the standard scheme one has either to operate at much reduced compression rates or the overall estimation performance substantially suffers from the dominance of model mismatch.

It is therefore important to evaluate the additional amount of sampling which is necessary cope in a stable way with such model uncertainties. The output signals to be sampled are not lying anymore in a fixed finite union of low–dimensional canonical subspaces but in a more complicated but compressible set. In this talk we focus on bilinear models and we discuss conditions which ensure additive complexity in input signals and model uncertainty. We demonstrate the relevance of this topic for sporadic communication in future cellular wireless networks and indicate possible extensions of existing random access strategies.

11:40–12:15 **Stable embedding of sparse convolutions**
Philipp Walk, Technische Universität München, Germany

Linear time (discrete) invariant (LTI) systems represent a fundamentaltransfer model present wireless communication, sampling and signal processing. In communication theory, it usually refers to a discrete convolution, where one input represents the impulse response of a fixed channel state and the other the data carrying transmit signal.

While Compressed Sensing of sparse signals has gained tremendous success in reducing sampling rates, it remains unknown, what reduction can be achieved in compressive sampling of the output of an LTI system with both sparse input data signals and sparse channels. Obviously, injectivity of the system is crucial to guarantee stable reconstruction of sparse signals from the output. In this talk we will establish a convolution inequality in the ℓ^2-norm for finite complex-valued sequences, where the lower and upper bounds solely depend on the size of the sequences support. By appropriately appending zeros to the signals this inequality holds for circular convolutions as well. Thus, we achieved a stability result which holds for any unknown but fixed f-sparse LTI system and for all s-sparse data signals in an ambient dimension n.

In conjunction with a suitable RIP property on the output set this allows a stable embedding of all s-sparse data signals in $O((2sf)\log n)$ dimensions with exponential high probability. Here, the measurement matrix is universal and holds for any f-sparse channel realization.

Museum Tours

- **Pergamon Museum**. Host of numerous exhibits ranging from Classical Antiquity to the Middle East and Islamic art. Most prominent are the monumental reconstructions of the Market Gate of Miletus and the Pergamon Altar. No German art museum attracts more visitors.
  Address: Bodestrasse 1-3, 10178 Berlin.
  Tickets: 12 €, discounted admission 6 €
  Web page: `http://www.smb.museum/`
- **Jewish Museum**. The spectacular building by Daniel Libeskind houses Europe's largest Jewish museum that guides the visitor through two thousand years of German Jewish history.
  Address: Lindenstrasse 9-14, 10969 Berlin.
  Tickets: 7 €, discounted admission 3.50 €
  Web page: `http://www.jmberlin.de/`

Both groups will meet on **Wednesday at 14:00** in front of the TU Berlin main building. Those who would like to go to the museums on their own should be there at 15:00 (please see the maps on pages 32-33).

From each of the museums, we will go jointly to the conference dinner.

Conference Dinner

The conference dinner will take place at 18:00 at **van Loon-Restaurantschiff**, Carl-Herz-Ufer 5, 10961 Berlin. The restaurant is on a boat on the river, 5-10 minutes walk from U-Bahnhof Prinzenstrasse (line U1) (see the map on page 33).

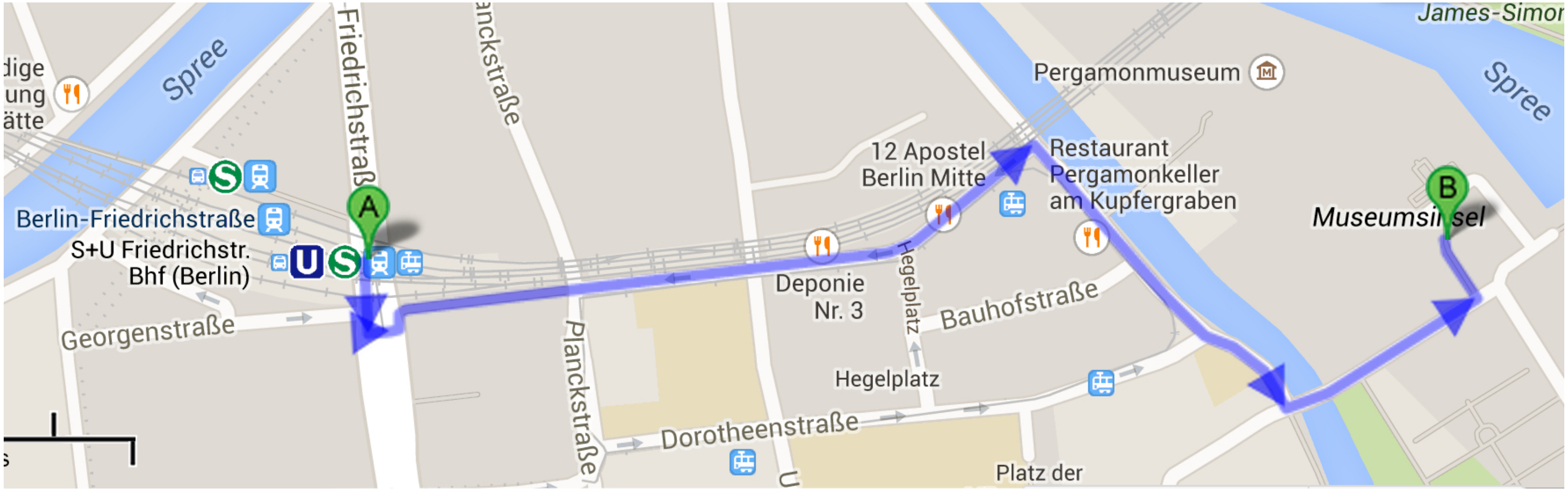
The participants will need to get back to their hotels on their own. Those staying near the university could take the following route: Walk to U-Bahnhof Prinzenstrasse (line U1) and take the U1 in the direction of Uhlandstrasse. On this line, one can get off at
a) Kurfürstendamm (and change to line U9 in direction Osloer Strasse for one stop, if one needs to go to S+U Zoologischer Garten),
b) the final station Uhlandstrasse.

Getting Around in Berlin

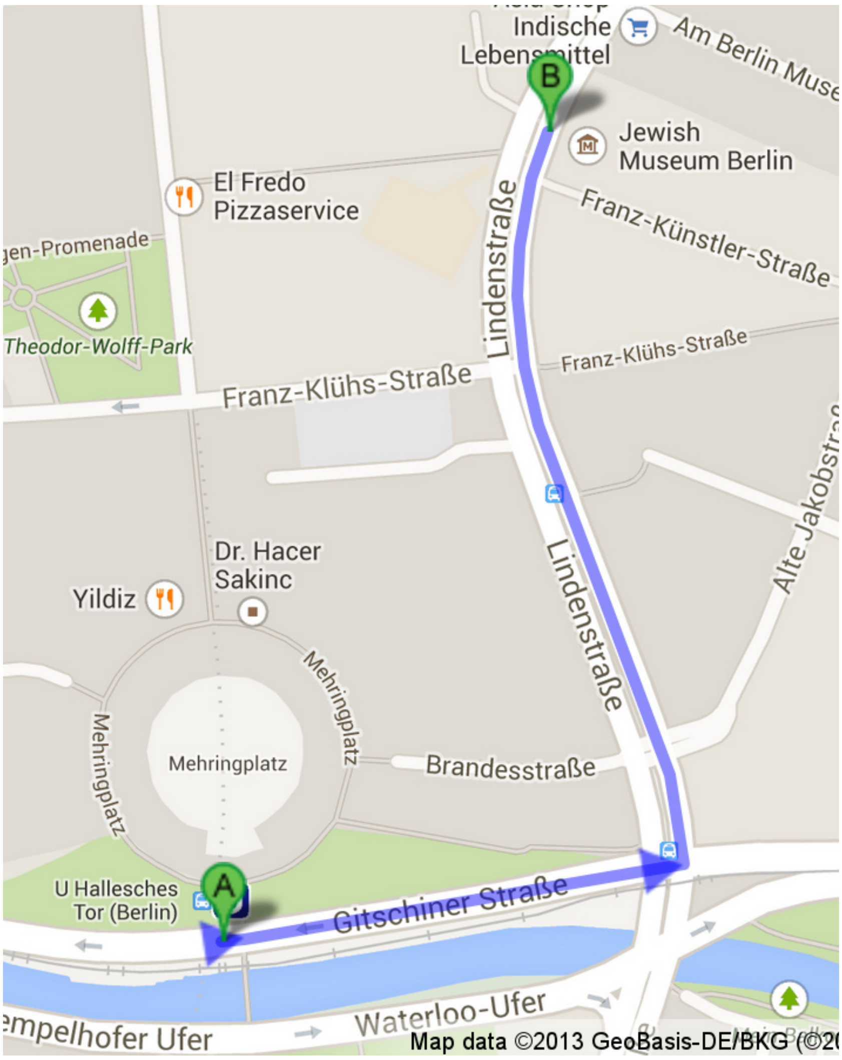
For finding the best routes on public transport, you can use the official web page **`www.bvg.de`**, or download the Android/iOS application **Fahrinfo Mobile**.

Additional Information

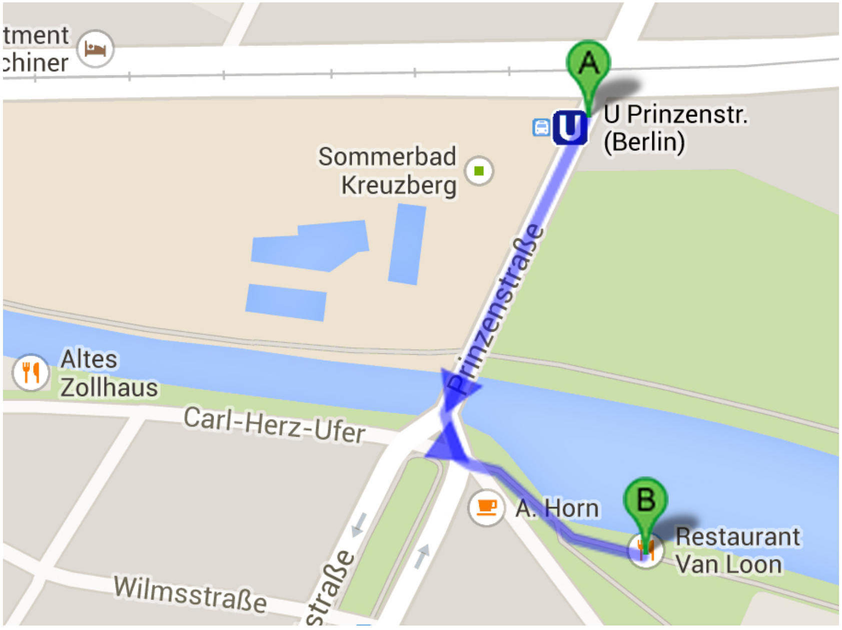
Additional information on sights, exhibitions, events, etc. can be found on the official website of Berlin: **`www.berlin.de`**.



From S+U Friedrichstrasse to Pergamon Museum



From U1-U6 Hallesches Tor to Jewish Museum



From U1 Prinzenstrasse to Conference Dinner

Places to Eat

This is only a selection of places close to the conference venue. See the map on the next page for locations.

Student Cafeterias / Quick Lunch: Warm dishes, sandwiches, salads, drinks etc, price range for a main dish 2 – 5 €.

Moderately Priced Restaurants: Reasonably priced hot meals, price range for a main dish 5 – 12 €.

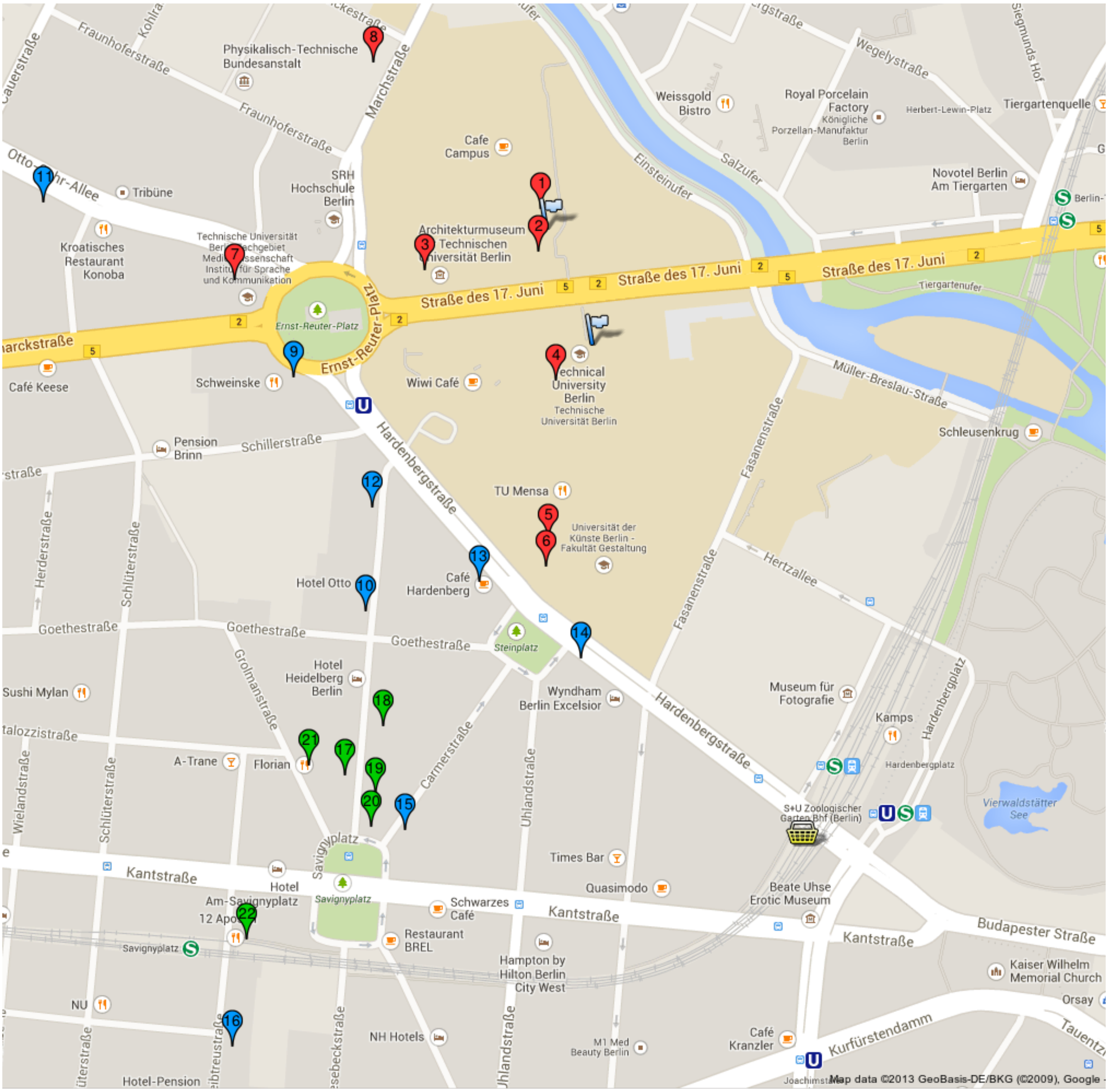
More Expensive Restaurants: More expensive meals, price range for a main dish 10+ € (normally between 10 and 20 €).

Quick Lunch		Moderately Priced	
1	Math Cafeteria - 9th floor	9	Pasta Eccetera
2	Math Cafeteria - ground floor	10	Schweinske
3	Cafeteria TU Ernst-Reuter-Platz	11	Tu Long (Chinese)
4	Cafeteria TU Hauptgebaeude	12	Manjurani (Indian)
5	TU Mensa Hardenbergstrasse	13	Café Hardenberg
6	Cafeteria TU Hardenbergstrasse	14	Filmbühne am Steinplatz
7	Cafeteria TU Skyline	15	Dicke Wirtin (Berlin Pub)
8	Cafeteria TU Marchstrasse	16	Café Bleibtreu

More Expensive	
17	Pratirio (Greek)
18	Buddha Republic (Indian)
19	Aida (Italian)
20	Mar y Sol (Spanish)
21	Florian (German)
22	12 Apostel (Italian)

For detailed description, menus and more, check our Google map:

`http://goo.gl/maps/Mlroa`



Fraunhoferstraße
Physikalisch-Technische Bundesanstalt
Marchstraße
Cafe Campus
SRH Hochschule Berlin
Otto-Suhr-Allee
Tribüne
Kroatisches Restaurant Konoba
Architekturmuseum Technischen Universität Berlin
Straße des 17. Juni
Ernst-Reuter-Platz
Café Keese
Schweinske
Wiwi Café
Technical University Berlin
Technische Universität Berlin
Pension Brinn
Schillerstraße
Hardenbergstraße
TU Mensa
Universität der Künste Berlin - Fakultät Gestaltung
Hotel Otto
Café Hardenberg
Goethestraße
Steinplatz
Hotel Heidelberg Berlin
Sushi Mylan
Grolmanstraße
Wyndham Berlin Excelsior
A-Trane
Florian
Carmerstraße
Uhlandstraße
Savignyplatz
Kantstraße
Times Bar
Quasimodo
Schwarzes Café
Restaurant BREL
Hampton by Hilton Berlin City West
NU
NH Hotels
Hotel-Pension
Weissgold Bistro
Royal Porcelain Factory
Königliche Porzellan-Manufaktur Berlin
Tiergartenquelle
Novotel Berlin Am Tiergarten
Einsteinufer
Salzufer
Wegelystraße
Tiergartenufer
Müller-Breslau-Straße
Schleusenkrug
Fasanenstraße
Hertzallee
Museum für Fotografie
Kamps
Hardenbergplatz
S+U Zoologischer Garten Bhf (Berlin)
Vierwaldstätter See
Beate Uhse Erotic Museum
Budapester Straße
Kaiser Wilhelm Memorial Church
Orsay
Café Kranzler
Kurfürstendamm
M1 Med Beauty Berlin
Map data ©2013 GeoBasis-DE/BKG (©2009), Google

Compressed Sensing and its Applications

MATHEON Workshop 2013

Special thanks to Tim Kovacs for sharing the booklet template.
Tim Kovacs, A latex style file for conference booklets. CSTR-12-005, Department of Computer Science. September 2012.