

# Reinhard Heckel

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## Research interests

Machine learning, signal and information processing, optimization, and statistics.

Current focus is on i) developing algorithms and theory for deep learning, in particular for solving signal and image reconstruction problems with deep learning, ii) learning from few and noisy examples, and iii) DNA data storage and DNA as digital information technology.

## Education

- 08/2010 - **ETH Zurich**, Zurich, Switzerland.
- 10/2014 Ph.D. in Electrical Engineering, **ETH medal for outstanding thesis**
  - Advisor: Prof. Helmut Bölcskei
- 09/2013 - **Stanford University**, Stanford, CA, United States.
- 12/2013 Visiting Ph.D. Student with Prof. Emmanuel Candès
- 10/2005 - **University of Ulm**, Ulm, Germany.
- 05/2010 Diploma (equiv. M.S. degree) in Electrical Engineering, **with Honors**.

## Awards

- ETH Zurich medal for outstanding Ph.D. thesis, 2015
- IBM first patent application invention achievement award, 2015
- Early Postdoc.Mobility fellowship from the Swiss National Science Foundation, 2014
- Best student paper award at the Int. Workshop on Comp. Systems Biology, 2012

## Academic experience

- 06/2019 - **Technical University of Munich**, Munich, Germany.
  - present Assistant Professor at the Department of Electrical and Computer Engineering
  - Rudolf Mössbauer Tenure Track Professor, TUM Institute of Advanced Studies
- 06/2019 - **Rice University**, Houston, TX.
  - present Adjunct Assistant Professor at the Department of Electrical and Computer Engineering
- 08/2017 - **Rice University**, Houston, TX.
  - 05/2019 Assistant Professor at the Department of Electrical and Computer Engineering
- 01/2016 - **University of California Berkeley**, Berkeley, CA.
  - 07/2017 Postdoc at the Department of Electrical Engineering and Computer Sciences
- 12/2014 - **IBM Research**, Zurich, Switzerland.
  - 12/2015 Researcher at the Department of Cognitive Computing & Computational Sciences
- 08/2010 - **ETH Zurich**, Zurich, Switzerland.
  - 11/2014 Research and teaching assistant at the Communication Technology Laboratory

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## Teaching

### At TUM

- Winter 2019 and 2020: Optimization and machine learning
- Winter 2020: Seminar on the foundations and robustness of deep learning
- Summer 2019 and 2020: Introduction to machine learning
- Summer 2020: Seminar on the foundation of deep learning in imaging science

### At Rice

- Fall 2017, Spring 2019: ELEC 577 Optimization for data science
- Fall 2018: ELEC 578 Introduction to machine learning
- Spring 2018: ELEC 631 Deep networks for inference and estimation, jointly taught with Richard Baraniuk

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## Funding

Total external funding awarded as an assistant professor: \$1,495,572

- NSF IIS Small “Actively learning from the crowd”, awarded 2018 as a single PI: \$474,322.
- NIH “Polycyclic aromatic hydrocarbons: Ultrasensitive detection, early life exposures-clinical outcomes (preterm births, chronic lung disease, and neurocognitive deficits), prevention, and remediation”, awarded 2019 as co-PI. Individual part: \$276,064.
- EU project “DNA-Fast light dRiven data technologY with multiplexed optical encoding and readout”, awarded 2020 as co-PI. Individual part: 324,780 Euro (\$ 388,558).
- DFG project “Theory of un-trained neural networks for image recovery”, awarded 2021 as single PI. 294,000 Euro (\$ 356,628).

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## Mentoring and student supervision

### Current group

- Mohammad Zalbagi Darestani, 2nd year PhD student at Rice
- Zhenwai Dai, 2nd year PhD student at Rice, co-advised with Anshumali Shrivastava
- Tobit Klug, 1st year PhD student at TUM
- Fatih Furkan Yilmaz, 3rd year PhD student at Rice

### Master student supervision at TUM

Lena Heidemann, Tobit Klug, Zi Yang, Yundi Zhang

### Undergraduate supervision at TUM

Jacob Geussen, Oleksii Khakhlyuk

### Master thesis supervision at ETH

Cécile Chenot, Celestine Dünner, Irene Pappalardo, Michael Tschannen

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## Service

### Organization of workshops/conferences

- Co-chair of the NeurIPS 2020 workshop “Deep Learning and Inverse Problems”
- Technical Area Chair for Adaptive Systems, Machine Learning, Data Analytics at the 2019 Asilomar conference
- Co-chair of the NeurIPS 2019 workshop “Solving inverse problems with deep networks: New architectures, theoretical foundations, and applications”

### Departmental service at Rice University

- Founded, acquired \$20,000 funding for, and co-running (with students from ECE, CS, and Stats) a weekly machine learning lunch series that averages more than 70 participants per week
- Member of the graduate committee
- Member of the ECE search committee for the faculty search in “Embedded Machine Learning”

### Member in PhD and Master committees

- Jangwon Kim, PhD in Bioengineering, Rice University, 2020
- Souptik Barua, PhD in ECE, Rice University, 2019
- Babhru Joshi, PhD in Applied Mathematics, Rice University, 2019
- Chris Metzler, PhD in ECE, Rice University, 2018
- CJ Barberan, Masters in ECE, Rice University, 2019
- Oscar Leong, Master in Applied Mathematics, Rice University, 2018
- Akash Kumar Maity, Masters in ECE Rice University, 2018
- Qiang Zhang, Masters in Applied Mathematics, Rice University, 2018

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## Publications

3 representative papers marked with \*

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### Preprints

- P1 M. Zalbagi Darestani and **R. Heckel**  
Accelerated MRI with Un-trained Neural Networks  
*arXiv:2007.02471*, Jul. 2020.
- P2 F. F. Yilmaz and **R. Heckel**  
Image recognition from raw labels collected without annotators  
*arXiv:1910.14634*, Oct. 2019.
- P3 W. Huang, **R. Heckel**, P. Hand, V. Voroninski,  
A provably convergent scheme for compressive sensing under random generative priors  
*under review at Foundations of Computational Mathematics*, *arXiv:1812.04176*, 2018.

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## Long papers in highly selective conferences

- L1 **R. Heckel** and F. F. Yilmaz  
Early stopping in deep networks: Double descent and how to eliminate it  
*ICLR 2021*
- L2 **R. Heckel** and M. Soltanolkotabi  
Compressive sensing with un-trained neural networks: Gradient descent finds the smoothest approximation  
*ICML 2020*
- \*L3 **R. Heckel** and M. Soltanolkotabi  
Denoising and regularization via exploiting the structural bias of convolutional generators  
*ICLR 2020*
- \*L4 **R. Heckel** and P. Hand  
Deep decoder: Concise image representations from untrained non-convolutional networks  
*ICLR 2019*
- L5 D. LeJeune, R. Baraniuk, and **R. Heckel**  
Adaptive estimation for approximate k-nearest-neighbor computations  
*AISTATS 2019*
- L6 **R. Heckel**, M. Simchowitz, K. Ramchandran, and M. Wainwright  
Approximate ranking from pairwise comparisons  
*AISTATS 2018*
- L7 **R. Heckel** and K. Ramchandran  
The sample complexity of online one-class collaborative filtering  
*ICML 2017*
- L8 **R. Heckel**, M. Vlachos, T. Parnell, and C. Dünner  
Scalable and interpretable product recommendations via overlapping co-clustering  
*ICDE 2017*
- L9 **R. Heckel** and M. Vlachos, “Private and right-protected big data publication: An analysis  
*SIAM Data Mining 2017*

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## Journal articles

- J1 I. Shomorony and **R. Heckel**  
DNA-Based Storage: Models and Fundamental Limits  
*IEEE Trans. Inf. Theory*, 2021
- J2 P. L. Antkowiak, J. Lietard, M. Zalbagi Darestani, M. Somoza, W. J. Stark, **R. Heckel\***, R. N. Grass\*  
Low cost DNA data storage using photolithographic synthesis and advanced information reconstruction and error correction  
*Nature Communications*, 2020 (\*=corresponding authors).

- J3 L. C. Meiser, J. Koch, P. L. Antkowiak, W. J. Stark, **R. Heckel**, R. N. Grass  
DNA synthesis for true random number generation  
*Nature Communications*, 2020.
- J4 **R. Heckel**, W. Huang, P. Hand, V. Voroninski,  
Deep denoising: Rate-optimal recovery of structured signals with a deep prior  
*Information and Inference: A Journal of the IMA*, 2020.
- J5 E. Bostan, **R. Heckel**, M. Chen, M. Kellman, L. Waller  
Deep Phase Decoder: Self-calibrating phase microscopy with an untrained deep neural network  
*Optica*, 2020.
- J6 R. Grass, **R. Heckel**, C. Dessimoz, W. J. Stark,  
Genomic encryption of digital data stored in synthetic DNA  
*Angewandte Chemie International Edition*, 2020.
- J7 L. Meiser, P. Antkowiak, J. Koch, W. Chen, A. X. Kohll, W. J. Stark, **R. Heckel\***  
R. N. Grass\* (\*=corresponding authors)  
Reading and writing digital data in DNA  
*Nature Protocols*, 2019, **featured on the cover of the January 2020 issue.**
- J8 **R. Heckel**, G. Mikutis, and R. N. Grass  
A Characterization of the DNA Data Storage Channel  
*Scientific Reports*, 2019.
- J9 W. Chen, A. Kohll, B. Nguyen, J. Koch, **R. Heckel**, W. J. Stark, L. Ceze, K. Strauss,  
R. N. Grass  
Combining data longevity with high storage capacity—layer-by-layer DNA encapsulated  
in magnetic nanoparticles  
*Advanced Functional Materials*, 2019.
- \*J10 **R. Heckel**, N. B. Shah, K. Ramchandran, and M. J. Wainwright  
Active ranking from pairwise comparisons and when parametric assumptions don't help  
*Annals of Statistics*, 2019.
- J11 **R. Heckel**  
An archive written in DNA  
*Nature Biotechnology*, 2018.
- J12 M. Vlachos, C. Duenner, **R. Heckel**, V.G. Vassiliadis, T. Parnell, K. Atasu  
Addressing interpretability and cold-start in matrix factorization for recommender systems  
*IEEE Trans. on Knowl. and Data Eng.*, 2018.
- J13 N. Antipa, G. Kuo, **R. Heckel**, B. Mildenhall, E. Bostan, R. Ng, L. Waller  
DiffuserCam: Lensless single-exposure 3D imaging  
*Optica*, 2018.

- J14 **R. Heckel** and M. Soltanolkotabi  
Generalized line spectral estimation via convex optimization  
*IEEE Trans. Inf. Theory*, 2018.
- J15 **R. Heckel**, M. Tschannen, and H. Bölcskei  
Dimensionality-reduced subspace clustering  
*Information and Inference: A Journal of the IMA*, 2017.
- J16 M. Vlachos, V.G. Vassiliadis, **R. Heckel**, A. Labbi  
Toward interpretable predictive models in B2B recommender systems  
*IBM Journal of Research and Development*, 2016.
- J17 **R. Heckel**, V. I. Morgenshtern, M. Soltanolkotabi  
Super-resolution radar  
*Information and Inference: A Journal of the IMA*, 2016.
- J18 **R. Heckel** and H. Bölcskei  
Robust subspace clustering via thresholding  
*IEEE Trans. Inf. Theory*, 2015.
- J19 D. Paunescu, C. A. Mora, L. Querci, **R. Heckel**, M. Puddu, B. Hattendorf, D. Günther, and R. N. Grass  
Detecting and number counting of single engineered nanoparticles by digital particle polymerase chain reaction  
*ACS Nano*, 2015, **selected by ACS as Editors Choice**.
- J20 R. Grass, **R. Heckel**, M. Puddu, D. Paunescu, and W. J. Stark  
Robust chemical preservation of digital information on DNA in silica with error-correcting codes  
*Angewandte Chemie International Edition*, 2015, **featured in Nature as research highlight, press coverage by BBC, CNN, and IEEE Spectrum**.
- J21 **R. Heckel** and H. Bölcskei  
Identification of sparse linear operators  
*IEEE Trans. Inf. Theory*, 2013.
- J22 **R. Heckel**, S. Schober, and M. Bossert  
Harmonic analysis of Boolean networks: Determinative power and perturbations  
*EURASIP J. Bioinform. Syst. Biol.*, 2013.
- J23 J. Klotz, **R. Heckel**, and S. Schober,  
Bounds on the average sensitivity of nested canalizing functions  
*PLoS ONE*, 2013.
- J24 S. Schober, D. Kracht, **R. Heckel**, and M. Bossert  
Detecting controlling nodes of Boolean regulatory networks  
*EURASIP J. Bioinform. Syst. Biol.*, 2011.

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## Refereed conference proceedings

- C1 S. Shin, **R. Heckel**, I. Shomorony “Capacity of the Erasure Shuffling Channel”,  
*ICASSP*, 2020.

- C2 **R. Heckel** “Signal recovery with un-trained convolutional neural networks”,  
*NeurIPS medical imaging workshop*, 2019.
- C3 Z. Dai and **R. Heckel** “Channel Normalization in Convolutional Neural Network avoids Vanishing Gradients”,  
*ICML Deep Phenomena Workshop*, 2019
- C4 I. Shomorony and **R. Heckel** “Capacity Results for the Noisy Shuffling Channel”,  
*ISIT*, 2019
- C5 F. Ong, **R. Heckel**, K. Ramchandran “A fast and robust paradigm for Fourier compressed sensing based on coded sampling”  
*ICASSP*, 2019
- C6 C. Metzler, A. Mousavi, **R. Heckel**, R. Baraniuk “Unsupervised Learning with Stein’s Unbiased Risk Estimator”,  
*International Biomedical and Astronomical Signal Processing (BASP) Frontiers workshop*, 2019, **best contribution award**.
- C7 **R. Heckel**<sup>\*</sup>, I. Shomorony<sup>\*</sup>, K. Ramchandran, and D. Tse “Fundamental Limits of DNA Storage Systems,”  
*ISIT*, 2017 (\* equal contribution).
- C8 **R. Heckel** and M. Soltanolkotabi, “Generalized Line Spectral Estimation for Radar and Localization,”  
*CoSeRa*, 2016, **invited paper**.
- C9 **R. Heckel**, “Super-resolution MIMO radar,”  
*ISIT*, 2016.
- C10 **R. Heckel**, M. Tschannen, and H. Bölcskei, “Subspace clustering of dimensionality reduced data,”  
*ISIT*, 2014.
- C11 A. Jung, **R. Heckel**, H. Bölcskei, and F. Hlawatsch, “Compressive nonparametric graphical model selection for time series,”  
*ICASSP*, 2014.
- C12 **R. Heckel**, E. Agustsson, and H. Bölcskei, “Neighborhood selection for thresholding based subspace clustering,”  
*ICASSP*, 2014.
- C13 **R. Heckel** and H. Bölcskei, “Noisy subspace clustering via thresholding,”  
*ISIT*, 2013.
- C14 **R. Heckel** and H. Bölcskei, “Subspace clustering via thresholding and spectral clustering,”  
*ICASSP*, 2013.
- C15 **R. Heckel** and H. Bölcskei, “Joint sparsity with different measurement matrices,”  
*Allerton*, 2012, **invited paper**.

- C16 **R. Heckel**, S. Schober, and M. Bossert, “Determinative power and tolerance to perturbations in Boolean networks,” *WCSB*, 2012, **best student paper award**.
- C17 **R. Heckel** and H. Bölcskei, “Compressive identification of linear operators,” *ISIT*, 2011.
- C18 S. Schober, **R. Heckel**, and D. Kracht, “Spectral properties of a Boolean model of the E. coli genetic network and its implication on network inference,” *WCSB*, 2010.
- C19 **R. Heckel**, S. Schober, and M. Bossert, “On random Boolean threshold networks,” *SCC*, 2010.
- C20 **R. Heckel** and S. Schober, “A Boolean genetic regulatory network created by whole genome duplication,” *WCSB*, 2009.

## Patents

- P1 **R. Heckel**, V. Vasileiadis, and M. Vlachos, “Method and system for identifying dependent components”, US Patent 20,160,063,392, 2016.
- P2 **R. Heckel** and M. Vlachos, “The obfuscation and protection of data rights”, US Patent 9,916,472, 2015.

## Book Chapters

- B1 **R. Heckel**, “Super-resolution radar imaging via convex optimization”, Chapter “Compressed Sensing based Radar Signal Processing”, 2019.

## Recent invited talks

- 2020 “Tutorial on Deep networks for inverse problems”, IEEE European School of Information Theory  
 “Image recovery with untrained convolutional neural networks”, Stanford SCIEN Colloquium  
 “Provable Image Recovery with Untrained Convolutional Neural Networks”, One World Mathematics of Information, Data, and Signals Seminar.  
 “Image recovery and recognition via exploiting the structural bias of neural networks”, Math FLDS / CPS seminar, University of Southern California (USC)
- 2019 “Denoising and regularization via exploiting the structural bias of convolutional generators”, Berkeley, Computational Imaging Lunch  
 “Denoising and regularization via exploiting the structural bias of convolutional generators”, Stanford, Information Systems Lab Colloquium  
 “Image recovery and restoration with neural networks and robust storage of information on DNA”, ETH, Institute for Chemical and Bioengineering Seminar  
 “Denoising and regularization with untrained neural networks”, Asilomar Conference on Signals, Systems, and Computers



- “Denoising and regularization via exploiting the structural bias of convolutional generators”, Allerton Conference on Communication, Control, and Computing
- “Deep Decoder: Concise image representations from untrained networks”, Math+X symposium on inverse problems and deep learning in space exploration
- “Regularizing inverse problems with untrained neural networks”, Machine Learning in Solid Earth Geoscience Workshop, Los Alamos
- “Deep Decoder: Concise image representations from untrained networks”, Information Theory and Applications Workshop, San Diego
- “Deep Decoder: Concise image representations from untrained networks”, University of Washington, Machine learning seminar
- 2018 “Deep Decoder: Concise image representations from untrained networks”, UIUC, Coordinate Science Lab, SINE Seminar
- “Deep Decoder: Concise image representations from untrained networks”, Winedale workshop, Windedale, Texas
- “Deep Decoder: Concise image representations from untrained networks”, Rice University, CAAM colloquium
- “Robust storage of information in DNA molecules”, Microsoft Research Redmond
- “Robust storage of information in DNA molecules”, EPFL, IC talk
- “Robust storage of information in DNA molecules”, Berkeley, Berkeley Laboratory for Information and System Sciences (BLISS) Seminar
- “Approximate ranking from pairwise comparisons”, Information Theory and Applications Workshop
- 2017 “Robust preservation of digital information on DNA with error-correcting codes”, UT Austin, DNA23 conference
- “Robustness and complexity tradeoffs in inference and learning”, Rice University
- “Robustness and complexity tradeoffs in inference and learning”, Cornell
- “Collection and preserving information efficiently and reliably”, Cornell Tech
- “Algorithms and theory for efficient data collection, information extraction, and preservation”, TU Munich
- “Super-resolution and resolution limits of computational imaging systems”, Berkeley, Computational Imaging Lunch
- “Active ranking from pairwise comparisons and when parametric models don’t help”, Berkeley, Berkeley Laboratory for Information and System Sciences (BLISS) Seminar
- “Active ranking from pairwise comparisons and when parametric models don’t help”, Information Theory and Applications Workshop
- 2016 Super-resolution radar, USC

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## Press coverage

- Aug. 2020 We stored the first Series of the German TV show “Biohackers” for Netflix on DNA. This was one of the first commercial applications of DNA storage, and received wide press coverage by the German media including the newspaper FAZ, a 8-minute feature in a national TV station, and a number of blogs such as <https://blocksandfiles.com> and <https://www.golem.de>.
- Oct. 2018 We stored Massive Attack’s music album Mezzanine on DNA. This was the first commercial application of DNA storage and received press coverage by **Weired** “Massive Attack are releasing an album in a new format: DNA”, and **Fortune** “Scientists are coding an electronic music masterpiece into DNA so it can last forever”, amongst others.
- Nov. 2015 BBC featured a video about us and the DNA storage project in the science news series “the genius behind”, the video was broadcasted at BBC worlds news, the channel with the largest audience of any channel: <http://www.bbc.com/future/story/20151122-this-is-how-to-store-human-knowledge-for-eternity>.
- Jan. 2015 Our work on robust DNA data storage was featured in Nature as research highlight and received press coverage by BBC, CNN, and IEEE Spectrum