Dr. Felix Voigtlaender

Ph.D. in Mathematics

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Personal information

Age 31 (Born: 4. November 1988 in Aachen, Germany)
Nationality German

Employment History

From June 2020 — **Senior Scientist**, University of Vienna (Austria)
Member of the group of Prof. Dr. Philipp Grohs

Feb. 2018–May 2020 — **Research assistant ("Akademischer Rat")**, Catholic University Eichstätt–Ingolstadt (Germany), Department of Scientific Computing
Member of the group of Prof. Dr. Götz Pfander

Apr. 2016–Jan. 2018 — **Research assistant (Post-Doc)**, TU Berlin (Germany), Applied Harmonic Analysis Group
Member of the group of Prof. Dr. Gitta Kutyniok
Researcher as part of the Horizon 2020 project "DEDALE" (*Data Learning on Manifolds and Future Challenges*)

Apr. 2013–Mar. 2016 — **Research assistant**, RWTH Aachen University (Germany), Lehrstuhl A für Mathematik
April 2013 until November 2015: PhD student, supervised by Prof. Dr. Hartmut Führ
December 2015 until March 2016: Post-Doc

Education

Apr. 2013–Nov. 2015 — **PhD student**, RWTH Aachen University (Germany)
PhD thesis: "Embedding Theorems for Decomposition Spaces with Applications to Wavelet Coorbit Spaces"
Supervisor: Prof. Dr. Hartmut Führ
Degree conferred: 17. December 2015
Grade: Summa cum laude

Oct. 2010–Mar. 2013 — **Master student in Mathematics**, RWTH Aachen University (Germany)
Overall grade: Excellent (1.0)
Thesis: "Spektralkalkül auf Gruppen von polynomialem Wachstum" ("Spectral calculus on groups of pol. growth")

Oct. 2007–Sept. 2010 — **Bachelor student in Mathematics**, RWTH Aachen University (Germany)
Overall grade: Excellent (1.0)
Thesis: "Integraldarstellung metaplektischer Operatoren" ("Integral representation of metaplectic operators")

Oct. 2007–Apr. 2012 — **Bachelor student in Computer Science**, RWTH Aachen University (Germany)
Overall grade: Excellent (1.1)
Thesis: "Advanced Trace-Based Analysis of Hybrid Programs"

Aug. 1999–Jun. 2007 — **Academic high school ("Gymnasium")**, Gymnasium Haus Overbach in Jülich/Barmen (Germany)
Completion with high school diploma ("Abitur")
Overall grade: 1.5 (on a scale of 1 (best) to 5 (worst))
Intensive courses: Mathematics and Physics

Experience in teaching

Oct. 2018–Feb. 2020 **Teaching as "Akademischer Rat" at the Catholic University Eichstätt–Ingolstadt**, *Germany*
Lecturer for the following courses:
- Mathematics of machine learning (Winter semester 2019/2020)
- Introduction to programming (Winter semester 2019/2020)
- Probability theory (Summer semester 2019)
- Overview of analysis and linear algebra (preparing prospective teachers for final exam) (Summer semester 2019)
- Integration theory (Winter semester 2018/2019)
- Introduction to programming (Winter semester 2018/2019)

Summer semester 2018 **Teaching assistant at the Catholic University Eichstätt–Ingolstadt**, *Germany*
Teaching assistant for the lecture *Ordinary differential equations*

July 2017 **Lecturer at the Summer School "Three Minicourses on Signal Analysis and Big Data"**, *Genoa, Italy*
Title of lecture series: "Sparsity Properties of Frames via Decomposition Spaces"

Oct. 2016–Jan. 2018 **Research fellow ("Wissenschaftlicher Mitarbeiter") at TU Berlin**, *Germany*
- Supervision of student seminar "Applied harmonic analysis" (Winter semester 2016/2017)
- Co-supervision of the following bachelor theses, jointly with Prof. Dr. Gitta Kutyniok:
  - Malte Wust: *Denoising using shearlets on the sphere* (Winter semester 2017/2018)
  - Matthias Möser: *Dynamical Sampling* (Winter semester 2017/2018)
  - Lukas Richter: *The lifting property for classical function spaces* (Summer semester 2017)

Oct. 2013–Feb. 2016 **Research fellow ("Wissenschaftlicher Mitarbeiter") at RWTH Aachen University**, *Germany*
Teaching assistant for the following courses:
- Winter semester 2015/2016: Analysis I
- Summer semester 2015: Harmonic Analysis II
- Winter semester 2014/2015: Analysis III
- Winter semester 2013/2014: Analysis I

Oct. 2008–Jan. 2013 **Student teaching assistant at RWTH Aachen University, Lehrstuhl A für Mathematik**, *Germany*
Student teaching assistant for the following courses:
- Winter semester 2012/2013: Functional analysis
- Winter semester 2011/2012: Topology
- Summer semester 2011: Ordinary differential equations
- Winter semester 2010/2011: Analysis III
- Summer semester 2010: Analysis II
- Winter semester 2009/2010: Analysis I
- Winter semester 2008/2009: Analysis for computer scientists

Prizes, Awards and Scholarships

2016 **Teaching award of the student council of mathematics at RWTH Aachen University**
For the best teaching assistant in mathematics in the academic year 2014/2015

2016 **Friedrich-Wilhelm Award 2016**
For the best PhD thesis in mathematics at RWTH Aachen University in the academic year 2015/2016

2014 **Friedrich-Wilhelm Award 2014**
For the best Master thesis in mathematics at RWTH Aachen University in the academic year 2013/2014

Oct. 2011–Mar. 2013 **Stipend of the education fund of the RWTH Aachen University ("Deutschlandstipendium")**

2009–2013 **Mentioning on the "Dean's List" recording the top 5% of best students at RWTH Aachen**

2009 **Selected for participation in the RWTH International Research Opportunity Program (IROP)**
Two month stay (June – August) at the Massachusetts Institute of Technology (MIT), Boston.
Participation in the working group "New Media Medicine" at the MIT Media Lab

Journal Publications

[1] P. Petersen, M. Raslan, and F. Voigtlaender. Topological properties of the set of functions generated by neural networks of fixed size. *Found. Comput. Math.*, 2020. doi:10.1007/s10208-020-09461-0.

[2] F. Voigtlaender. Embeddings of decomposition spaces. *Accepted for publication in Mem. Am. Math. Soc.* arXiv:1605.09705.

[3] P. Petersen and F. Voigtlaender. Equivalence of approximation by convolutional neural networks and fully-connected networks. *Proc. Amer. Math. Soc.*, 148:1567–1581, 2020. doi:10.1090/proc/14789.

[4] D. Bytchenkoff and F. Voigtlaender. Design and properties of wave packet smoothness spaces. *J. Math. Pures Appl.*, 133:185–262, 2020. doi:10.1016/j.matpur.2019.05.006.

[5] F. Sureau, F. Voigtlaender, M. Wust, J.-L. Starck, and G. Kutyniok. Learning sparse representations on the sphere. *Astron. Astrophys.*, 621:A73, 2019. doi:10.1051/0004-6361/201834041.

[6] P. Petersen and F. Voigtlaender. Optimal approximation of piecewise smooth functions using deep ReLU neural networks. *Neural Netw.*, 108:296–330, 2018. doi:10.1016/j.neunet.2018.08.019.

[7] H. G. Feichtinger and F. Voigtlaender. From Frazier-Jawerth characterizations of Besov spaces to Wavelets and Decomposition spaces. *Contemp. Math.*, 693:185–216, 2017. doi:10.1090/conm/693/13927.

[8] J. Fell, H. Führ, and F. Voigtlaender. Resolution of the wavefront set using general continuous wavelet transforms. *J. Fourier Anal. Appl.*, 22(5):997–1058, 2016. doi:10.1007/s00041-015-9445-7.

[9] D. Böhme, M. Geimer, L. Arnold, F. Voigtlaender, and F. Wolf. Identifying the root causes of wait states in large-scale parallel applications. *ACM Trans. Parallel Comput.*, 3(2):11:1–11:24, July 2016. doi:10.1145/2934661.

[10] H. Führ and F. Voigtlaender. Wavelet coorbit spaces viewed as decomposition spaces. *J. Funct. Anal.*, 269(1):80–154, 2015. doi:10.1016/j.jfa.2015.03.019.

Book Chapters

[11] S. Dahlke, F. De Mari, E. De Vito, L. Sawatzki, G. Steidl, G. Teschke, and F. Voigtlaender. On the atomic decomposition of coorbit spaces with non-integrable kernel. In *Landscapes of Time-Frequency Analysis*, chapter 4, pages 75–144. Birkhäuser, Cham, 2019. doi:10.1007/978-3-030-05210-2_4.

Conference Proceedings

[12] F. Voigtlaender and P. Petersen. Approximation in $L^p(\mu)$ with deep ReLU neural networks. In *2019 13th International conference on Sampling Theory and Applications (SampTA)*, 2019. doi:10.1109/SampTA45681.2019.9030992.

[13] A. Caragea, D.G. Lee, F. Philipp, and F. Voigtlaender. A quantitative Balian-Low theorem for subspaces. In *2019 13th International conference on Sampling Theory and Applications (SampTA)*, 2019. doi:10.1109/SampTA45681.2019.9030951.

[14] P. Petersen, M. Raslan, and F. Voigtlaender. Unfavorable structural properties of the set of neural networks with fixed architecture. In *2019 13th International conference on Sampling Theory and Applications (SampTA)*, 2019. doi:10.1109/SampTA45681.2019.9030975.

[15] A. Caragea, D.G. Lee, F. Philipp, and F. Voigtlaender. Time-frequency shift invariance of Gabor spaces. In *2019 13th International conference on Sampling Theory and Applications (SampTA)*, 2019. doi:10.1109/SampTA45681.2019.9030919.

[16] P. Petersen, M. Raslan, and F. Voigtlaender. The structure of spaces of neural network functions. In *Wavelets and Sparsity XVIII*, pages 144–151. International Society for Optics and Photonics, SPIE, 2019. doi:10.1117/12.2528313.

[17] F. Voigtlaender. Understanding X-let sparsity via decomposition spaces. In *2017 12th International Conference on Sampling Theory and Applications (SampTA)*, pages 523–527, July 2017. doi:10.1109/SampTA.2017.8024402.

[18] J. Fell, H. Führ, and F. Voigtlaender. Resolution of the wave front set using general wavelet transforms. In *2015 11th International Conference on Sampling Theory and Applications (SampTA)*, pages 332–336, May 2015. doi:10.1109/SampTA.2015.7148907.

Preprints

[19] J.L. Romero, J.T. van Velthoven, and F. Voigtlaender. On dual molecules and convolution-dominated operators. *arXiv:2001.09609*, 2020.

[20] J. M. Almira, P.E. Lopez de Teruel, D.J. Romero-Lopez, and F. Voigtlaender. Negative results for approximation using single layer and multilayer feedforward neural networks. *arXiv:1810.10032v3*, 2020.

[21] J.L. Romero, J.T. van Velthoven, and F. Voigtlaender. Invertibility of frame operators on Besov-type decomposition spaces. *arXiv:1905.04934*, 2019.

[22] R. Gribonval, G. Kutyniok, M. Nielsen, and F. Voigtlaender. Approximation spaces of deep neural networks. *arXiv:1905.01208*, 2019.

[23] A. Caragea, D.G. Lee, F. Philipp, and F. Voigtlaender. Time-frequency shift invariance of Gabor spaces with an S_0-generator. *arXiv:1904.12345*, 2019.

[24] A. Caragea, D.G. Lee, F. Philipp, and F. Voigtlaender. A quantitative subspace Balian-Low theorem. *arXiv:1904.12250*, 2019.

[25] F. Voigtlaender. A general version of Price's theorem. *arXiv:1710.03576*, 2017.

[26] F. Voigtlaender and A. Pein. Analysis sparsity vs. synthesis sparsity for α-shearlets. *arXiv:1702.03559*, 2017.

[27] F. Voigtlaender. Structured, compactly supported Banach frame decompositions of decomposition spaces. *arXiv:1612.08772*, 2016.

[28] F. Voigtlaender. Embeddings of Decomposition Spaces into Sobolev and BV Spaces. *arXiv:1601.02201*, 2016.

Invited talks at international conferences and workshops

2019 **Workshop "MAIA 2019" (Multivariate Approximation and Interpolation with Applications)**
Erwin Schrödinger Institute, Vienna, Austria, 30. August 2019
"Approximation in $L^p(\mu)$ with deep ReLU neural networks"

2019 **Conference "12th ISAAC Congress" (International Society for Analysis, its Applications and Computations)**
Aveiro, Portugal, 1. August 2019
"Invertibility of frame operators on Besov-type decomposition spaces"

2019 **Congress "GAMM 2019" (90th annual meeting of the International Association of Applied Mathematics and Mechanics)**
Vienna, Austria, 18. February 2019
"Approximation spaces of deep neural networks"

2018 **Conference "IWOTA 2018" (International Workshop on Operator Theory and its Applications)**
Shanghai, China, 23. July 2018
"Analyzing sparsity properties of frames using decomposition spaces"

2018 **Workshop "WDI^2—Approximation Theory and Applications"**
Munich, Germany, 20. July 2018
"Approximation theoretic properties of deep ReLU neural networks"

2016 **Conference "Coherent States and their Applications: A Contemporary Panorama"**
CIRM, Marseille, France, 15. November 2016
"Shearlets: Theory, applications and generalizations"

Colloquium talks

2019 **Zurich Colloquium in Applied and Computational Mathematics**
Zurich, Switzerland, 6. March 2019
"Understanding sparsity properties of frames using decomposition spaces"

2019 **Colloquium at the mathematics institute of the Osnabrück University**
Osnabrück, Germany, 9. January 2019
"Approximation Theoretic Properties of Deep ReLU Neural Networks"

2017 **Zurich Colloquium in Applied and Computational Mathematics**
Zurich, Switzerland, 15. November 2017
"Optimal approximation of piecewise smooth functions using deep ReLU neural networks"

Contributed talks at international conferences and workshops

2019 — **Conference "SampTA 2019" (Sampling Theory and Applications)**
Bordeaux, France, 12. July 2019
"Approximation in $L^p(\mu)$ with deep ReLU neural networks"

2018 — **Conference "Strobl18" (Harmonic Analysis and Applications)**
Strobl, Austria, 7. June 2018
"A Guided Tour of Decomposition Spaces"

2018 — **Oberwolfach Workshop "Applied Harmonic Analysis and Data Processing"**
Oberwolfach, Germany, 28. February 2018
"Approximation Properties of Deep ReLU Networks"

2017 — **Conference "NPFSA-2017" (New perspectives in the theory of function spaces and applications)**
Będlewo, Poland, 18. September 2017
"Structured Banach frame decompositions of decomposition spaces"

2017 — **Conference "SampTA 2017" (Sampling Theory and Applications)**
Tallinn, Estonia, 7. July 2017
"Understanding X-let sparsity via decomposition spaces"

2017 — **Conference "ATFA17" (Aspects of Time-Frequency Analysis)**
Politecnico di Torino, Turin, Italy, 5. June 2017
"Structured Banach frame decompositions of decomposition spaces"

2016 — **Conference "FSDONA" (Function spaces, differential operators and nonlinear analysis)**
Charles University, Prague, Czech Republic, 8. July 2016
"Embeddings of decomposition spaces"

2016 — **International Workshop on Mathematical Imaging and Emerging Modalities**
Osnabrück, Germany, 30. June 2016
"Embeddings of decomposition spaces"

2016 — **Conference "Strobl 2016" (Time-Frequency Analysis and Related Topics)**
Strobl, Austria, 6. June 2016
"Embeddings of decomposition spaces"

2015 — **Conference "SampTA 2015" (Sampling Theory and Applications)**
American University, Washington D.C., USA, 27. May 2015
"Resolution of the Wave Front Set using general Wavelet Transforms"

2014 — **Conference "Function Spaces and Harmonic Analysis"**
CIRM, Marseille, France, 28. October 2014
"Embeddings between decomposition spaces"

2014 — **Conference "Strobl 2014" (Modern Time-Frequency Analysis)**
Strobl, Austria, 4. June 2014
"Coorbit spaces as decomposition spaces"

Seminar talks

2019 — **"Deep Learning Seminar" at the University of Vienna**
Vienna, Austria, 2. October 2019
"Approximation theory of neural networks — from the concrete to the abstract"

2019 — **"Deep Learning Seminar" at the University of Vienna**
Vienna, Austria, 26. February 2019
"Topological properties of the set of neural networks of fixed size"

2018 — **Graduate seminar "Dynamics" at TU Munich**
Munich, Germany, 26. November 2018
"Approximation theoretic properties of deep ReLU neural networks"

2018 — **Graduate seminar "Optimization and Data Analysis" at TU Munich**
Munich, Germany, 12. November 2018
"Understanding sparsity properties of frames using function spaces"

2018 — **Seminar of the working group "Mathematics of Computation" at the DTU Copenhagen**
DTU Copenhagen, Copenhagen, Denmark, 10. October 2018
"Approximation theoretic properties of deep ReLU neural networks"

2018

"Harmonic Analysis and Signal Processing Seminar" of the Courant Institute of Mathematical Sciences
New York University, New York City, USA, 26. September 2018
"Approximation theoretic properties of deep ReLU neural networks"

2018

"Applied Mathematics" seminar at Yale University
Yale University, New Haven, CT, USA, 25. September 2018
"Understanding sparsity properties of frames using function spaces"

2018

Seminar of the Acoustics Research Institute (Vienna)
Acoustics Research Institute, Vienna, Austria, 21. February 2018
"Describing sparsity properties of frames using function spaces"

2017

Graduate seminar "Advanced Topics in PDE and Harmonic Analysis" at the University of Bonn
Bonn, Germany, 24. November 2017
"Understanding sparsity properties of frames using decomposition spaces"

2017

Seminar "Mathematics of Computation" at the University of Bonn
Bonn, Germany, 23. November 2017
"Optimal approximation of piecewise smooth functions using deep ReLU neural networks"

2014

Seminar of the Analysis group at the Friedrich Schiller University Jena
Jena, Germany, 12. November 2014
"Embeddings between decomposition spaces"