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My passion is the development and mathematical analysis of fast numerical methods for the solution of computationally challenging physical problems, which are encountered in a whole variety of application areas from numerical weather and climate prediction, over ice sheet modelling all the way to quantum chemistry and the simulation of fundamental particle interactions. I have a diverse background in theoretical physics, atmospheric modelling and applied mathematics and more than five years of experience in Scientific- and High-Performance Computing with particular focus on the development and implementation of complex numerical algorithms on massively parallel supercomputers, including novel architectures such as GPUs. In addition to the design and analysis of optimised algorithms I am strongly interested in the practical implementation of these methods in "real-life" applications such as operational forecast models.

1 Professional and Research Experience

(See also section 6 for further details.)

- *Sep 2011 - present:* **Research Associate (PostDoc, funded by NERC)**
  Topic: massively parallel elliptic solvers in numerical weather- and climate prediction
  Dept. of Mathematical Sciences, University of Bath (PI: Prof. Rob Scheichl)
  The main focus of my current research is the development of highly scalable solvers for very large elliptic PDEs in Numerical Weather- and Climate- Prediction. I implemented an optimised geometric multigrid algorithm and demonstrated its scalability and superior performance on up to 65536 cores of the HECToR supercomputer for problems with more than 10 billion degrees of freedom [1]. I also developed highly efficient CUDA-C implementations of matrix-free preconditioned Conjugate Gradient- and multigrid- solvers on GPU architectures [2] and used them to solve systems with $0.5 \cdot 10^{12}$ unknowns on the Titan supercomputer (#2 in the www.top500.org list, Jun '14) [12]. I extended the mathematical analysis of the tensor-product multigrid algorithm in [Börm and Hiptmair, 1999] to more general PDEs arising in atmospheric models and generalised the implementation by using the C++ DUNE library framework [13]. Following the success of this project I collaborate with the Met Office to integrate the solver into their operational forecast model. I also work with colleagues at Imperial College to integrate multigrid solvers into performance portable software packages for unstructured grid computations.

- *Nov 2009 - Aug 2011:* **Atmospheric Dispersion Scientist**
  UK Met Office, Exeter (line manager: Dr. Matthew Hort)
  I was responsible for the implementation and testing of the OpenMP parallelisation in the NAME atmospheric dispersion model, which uses Monte Carlo methods to predict the spread and dispersion of pollutants in the atmosphere. My work resulted in a tenfold speedup of the operational model for the prediction of atmospheric pollutants in a real life scenario on a single CPU [3]. I also contributed significantly to the development of a new operational emergency response system for volcanic ash applications. I continue to collaborate with the Met Office atmospheric dispersion group on the development of multilevel Monte Carlo methods for the NAME dispersion model. Together with Dr. Tony Shardlow and Prof. Rob Scheichl I recently demonstrated the superior algorithmic performance of the method for the solution of SDEs in Lagrangian dispersion models [14].

- *Sep 2006 - Nov 2009:* **PhD in computational particle physics**
  University of Edinburgh (supervisor: Dr. Alistair Hart)
  I used and extended a parallel Python/Fortran code to calculate radiative corrections to heavy quark processes in Quantum Chromodynamics discretised on a space-time lattice (Lattice QCD). My calculations reduced numerical errors as they allowed the inclusion of sub-gridscale processes which can not be resolved explicitly with currently available lattice spacings. These calculations are based on Monte Carlo methods and have led to improved predictions for a range of experimentally observable quantities as described in our publications [4, 5, 6, 7].

2 Education

- *Summer 2005 - Aug 2006:* **Diploma[1] thesis in physics (with distinction)**
  University of Bonn, Germany (supervisors: Prof. Ulf-G. Meißner, Prof. Bastian Kubis)

  For my dissertation I carried out a one year research project in theoretical particle physics. Based on a Chiral expansion I used a numerical phase space integrator to predict the form factors of radiative Kaon decays and published the results in [8, 9].

- *Sep 2000 - Aug 2006:* **Undergraduate studies in physics**
  University of Siegen (Vordiplom Apr 2002), University of Bonn (May 2002 - Aug 2006)

  As an undergraduate student I was funded by a highly competitive Scholarship of the "Studienstiftung des Deutschen Volkes"[2].

- *Sep 2003 - Jun 2004:* **Exchange student, University of Edinburgh**
  funded by a highly competitive Scholarship of DAAD (German Academic Exchange Service[3])

  In addition to attending lectures in theoretical- and particle physics I took the initiative to carry out a research project in computational particle physics. Supervised by Dr. Alistair Hart I studied the locality properties of discretised fermion actions. For this I numerically approximated functions of large sparse matrices with randomly varying coefficients and analysed their spectrum and eigenvectors. I independently developed a C-code for the statistical analysis of a set of gauge field configurations. We published our results in [10].

- *Aug 2000 - Oct 2000:* **Scientific Internship (multigrid methods)**
  Institute for Algorithms and Scientific Computing (SCAI), GMD[4], St Augustin

  Before starting my undergraduate studies I took the initiative to gain first experience in applied mathematics through an internship in a research lab. After mastering the basic theory of the multigrid method I implemented and tested a simple multigrid algorithm in C++.

- *Aug 1999 - Jul 2000:* **Zivildienst[5]**
  Gillerbergheim, Hilchenbach

- *May 1999:* **Abitur[6](Grade 1.0 (very good), best student in a class of around 100)**
  Fürst-Johann-Moritz Gymnasium Siegen

  My main subjects were mathematics and physics and I regularly participated in mathematical competitions up to the federal level. I later volunteered to organise training weekends for younger students where I gave regular talks and tutorials.

[1] Title awarded upon completion of German undergraduate degree equivalent to five year Masters degree

[2] German National Academic Foundation, http://www.studienstiftung.de/en

[3] Deutscher Akademischer Austauschdienst, https://www.daad.org

[4] "Gesellschaft für Mathematik und Datenverarbeitung", now part of the "Fraunhofer Gesellschaft" for Applied Research http://www.scai.fraunhofer.de/en.html

[5] Community service as alternative to military service

[6] Diploma from German secondary school qualifying for university admission

3 Summary of Research Interests and Areas of Expertise

- **Scientific Computing**
  - Massively Parallel Algorithms
  - Parallel Programming with MPI, OpenMP, CUDA
  - GPUs and Novel Chip Architectures, GPU clusters
- **Numerical Analysis, Stochastic Modelling and Iterative Solvers for Large Elliptic PDEs**
  - Krylov Subspace Methods
  - (Parallel) Multigrid and Multilevel Algorithms
  - Monte Carlo Methods
  - Stochastic Differential Equations
  - Elliptic PDEs in Geophysical Modelling
- **Atmospheric Modelling**
  - Numerical Weather- and Climate Prediction
  - Atmospheric Dispersion Models
- **Computational- and Theoretical Particle Physics**
  - Lattice QCD (quantum field theory for strongly interacting nuclear constituents)
  - Effective Theories and Chiral Expansions (ChPT)
  - Automated Perturbation Theory and Monte Carlo methods
- **Scientific Software development**
  - C++, Fortran, Python, Java, Object Oriented Programming, Linux scripting
  - Numerical Libraries (BLAS, LAPACK, DUNE, hypre, firedrake, PyOP2, PETSc)

4 Student Supervision

MSc student projects at the Edinburgh Parallel Computing Centre (EPCC)

- *Jan-Aug 2011*: Mr. Kingsley Gale-Sides:
  "GPU implementation of atmospheric dispersion models"
- *Jan-Aug 2012*: Mr. Sinan Shi:
  "GPU implementation of elliptic solvers in NWP"

For both projects, which were jointly supervised by Ms. Xu Guo (EPCC) and me, I wrote the initial project proposal and co-supervised the students over a six-month period, with weekly meetings in the last three months. The project with Mr. Sinan Shi was so successful that we published the results in [2].

MPhil and PhD student projects, University of Bath

- *Sep 2012 - Sep 2013*: Ms. Sarah Cook (MPhil project):
  "Multilevel Monte Carlo methods in atmospheric dispersion modelling"
- *Since Sep 2014*: Mr. Grigoris Katsiolides (PhD project):
  "Multilevel Monte Carlo methods in atmospheric dispersion modelling"

I am the joint supervisor on these projects together with Prof. Rob Scheichl. The work is carried out in close collaboration with Dr. David Thomson, Dr. Ben Devenish and Dr. Elena Meneguz in the Atmospheric Dispersion Group at the Met Office. As a former member of the group my expertise was crucial in establishing a link between the university and the industrial partner. The ultimate goal will be to demonstrate the performance of multilevel Monte Carlo (MLMC) methods in the Met Office's operational dispersion model NAME. Together with Dr. Tony Shardlow we have also recently submitted first results of closely related work on MLMC methods for publication in [14].

MSc student project, University of Bath

- *Oct 2013 - Sep 2014*: Mr. William Saunders:
  “GPU implementation of solvers for the shallow water equations”

Together with Prof. Rob Scheichl I supervised this project on the GPU implementation of solvers for the shallow water equations using mimetic discetisations on regular grids. The performance of both explicit- and implicit time stepping methods was compared and the scalability of a CUDA-C implementation was studied on the EMERALD supercomputer. My experience in atmospheric modelling and in-depth knowledge of GPU architectures was crucial for the planning and execution of the project. The work is carried out in collaboration with Dr. Nigel Wood and Dr. Tom Melvin at the Dynamics Research Group at the Met Office.

Other student projects

- *2013*: Mr. Kait Kasak (Tartu, main supervisor: Prof. Eero Vainikko):
  “GPU parallelisation of tridiagonal solvers”

My knowledge was important for establishing the goal of this project, which is the development of a matrix-free parallel tridiagonal solver on GPUs. The method can then be used in the smoother for the tensor-product multigrid solver in [Börm and Hiptmair, 1999], which is a highly efficient algorithm for solving anisotropic PDEs in “flat” domains. I have provided significant scientific input for this project and built up links with industry and GPU specialists in this area (nVidia, group of Prof. Mike Giles (Oxford)).

5 Teaching Experience

- *Spring terms 2012, 2013 and 2014*: **Teacher**:
  Final Year & MSc course on Scientific Computing, University of Bath
  I jointly taught the course together with Prof. Robert Scheichl (15 lectures/12 tutorials in total, 7 lectures/3 tutorials on parallel computing taught by me) in 2012 and 2014. In addition to providing support to students during computer sessions and providing feedback for coursework and programming exercises I also delivered four lectures in 2013. In 2012 I initiated the design of a new student assignment on the parallelisation of a shallow water model and contributed substantially to the writing of the problem specification.
- *Autumn term 2008/09*: **Lab demonstrator**:
  “Advanced Computer simulation” course, University of Edinburgh
  As a lab demonstrator for this Java based course at the University of Edinburgh I provided face-to-face feedback on student exercises. The course covered topics from symbolic computer algebra to the numerical integration of simple dynamical systems and Monte Carlo methods.
- *2005-2008*: **Student tutor**:
  various courses, University of Bonn / Edinburgh
  I frequently worked as a tutor for student tutorials at the Universities of Bonn and Edinburgh. I covered a wide range of courses in Particle Physics, Advanced Quantum Physics, Mathematical Methods and Electrodynamics.

6 Recent Collaborative Research Projects

In the following I describe the achievements of several research projects which I was involved in over the last years. To emphasise the collaborative nature of these projects I highlighted my UK based and international *collaborators*.

GungHo! project: Development of a new dynamical core for the Unified Model

As a PostDoc at the University of Bath the focus of my current research is the development of fast and massively parallel elliptic solvers for the NERC funded GungHo! project. This Met Office led project is a collaboration between several UK universities, research institutes and the Met Office. My research into the scalability of elliptic solvers for the pressure correction equation in semi-implicit semi-Lagrangian time-stepping is vital for the success of this visionary project, whose aim is the development of a highly scalable dynamical core for the Met Offices NWP model. I was able to demonstrate the scalability of the elliptic solvers for a representative model equation, which was one of the key questions regarding the feasibility of implicit time stepping methods. Over the last 3 years I have frequently presented my work both at national project meetings and international conferences (see section 11) and published them in the literature [1], [12, 13]. To carry out my research I collaborate directly with a wide range of members of the project team, in particular: *Dr. Nigel Wood*, *Dr. Thomas Allen*, *Dr. Markus Gross (Met Office)* on the identification of suitable model equations, *Dr. Stephen Pickles*, *Dr. Rupert Ford (STFC)*, *Dr. Graham Riley (University of Manchester)* on computational aspects, and *Dr. John Thuburn (University of Exeter)*, *Dr. David Ham*, *Dr. Lawrence Mitchell (Imperial College)*, *Dr. Colin Cotter (Imperial)* on the development and implementation of multigrid solvers. Currently I am directly involved in the design of suitable solver algorithms and in the efficent implementations of finite element kernels in the newly developed operational model code.

DUNE- and hypre- implementation of massively parallel elliptic solvers

Together with *Dr. Andreas Dedner (University of Warwick)*, who is one of the core developers of the Distributed and Unified Numerics Environment (DUNE)[7] [Bastian et al., 2008b, Bastian et al., 2008a], I work on the implementation of a massively parallel multigrid solver on spherical tensor-product grids which are encountered in many areas of geophysical modelling in “flat” domains. Recently we demonstrated the excellent performance and scalability of the solver for elliptic PDEs encountered in atmospheric modelling [13]. I analysed the convergence of the method mathematically by extending the tensor-product multigrid theory in [Börm and Hiptmair, 1999] to three dimensional geometries and approximately factorising coefficient functions which are encountered in atmospheric models.

To test existing solvers in the DUNE library, I visited the group of *Prof. Peter Bastian (Heidelberg, Germany)* for two weeks in December 2011 and collaborated with *Dr. Markus Blatt*, the main developer of the algebraic multigrid solver in the library. In July/August 2012 I spent four week at LLNL (California) to work with *Dr. Robert Falgout*, *Dr. Ulrike Mayer-Yang* and other developers of the hypre library[8] [Falgout and Yang, 2002]. During this time I tested the performance of the BoomerAMG algebraic multigrid solver for the pressure correction in atmospheric applications.

Multi-GPU implementation of elliptic solvers

Since Feb 2013 I work together with *Prof. Eero Vainikko (University of Tartu, Estonia)* on the multi-GPU implementation of iterative solvers in CUDA-C. Together with *Dr. Benson Muite (KAUST, Saudi Arabia & Tartu)* we have recently shown the parallel scalability of my handwritten preconditioned Conjugate Gradient- and multigrid- solvers on the EMERALD cluster and on TITAN (#2 in the top500.org list of supercomputers in June 2014) on up to several thousand GPUs. Developing a handwritten matrix-free implementation which is tailored to the specifics of the GPU architecture was crucial to achieve optimal speedup. For the CG solver my implementation is about four times faster than a matrix explicit CSR implementation which uses standard CUDA library components. We are able to solve systems with up to half a trillion ($0.5 \cdot 10^{12}$) unknowns by utilising a significant fraction of the systems's peak performance for memory-bound applications [12]. The solvers use between 25% and 50% of the theoretical peak memory bandwidth, which is the most reliable performance indicator for memory-bound codes. The achieved floating point performance

[7]The Distributed and Unified Numerics Environment (DUNE), http://www.dune-project.org/

[8]High Performance Preconditioners (hypre), http://acts.nersc.gov/hypre/

was 0.78 petaFLOPs, which has to be compared to the theoretical peak of the full machine (27 petaFLOPs). As far as we are aware this is the first study of elliptic solvers on this scale on GPU clusters.

Performance portable solvers for mixed finite element discretisations of PDEs

Mimetic finite element discretisations of the fundamental equations of fluid dynamics can improve the stability and accuracy of numerical forecast models. Together with *Dr. David Ham*, *Dr. Colin Cotter* and *Dr. Lawrence Mitchell (Imperial College)* I currently develop a matrix-free solver for a mixed formulation of the Helmholtz equation encountered in atmospheric modelling. The code is implemented in the performance portable PyOP2/firedrake framework [Markall et al., 2013], and uses the iterative solver algorithms from the PETSc library `http://www.mcs.anl.gov/petsc/`. The firedrake library allows rapid development of the numerical algorithms in Python while automatically optimising performance critical iterations over the computational grid in efficient C kernel code. My main contribution to this project is the development of a matrix-free multigrid preconditioner for the pressure corrections equation on unstructured grids, both for lowest order $DG_0 + RT_0$ finite elements and for higher order $DG_1 + BDFM_1$ discretisations where I developed and tested suitable velocity mass lumping techniques.

Multigrid solvers for ENDGame

In addition to the more long-term work on the GungHo! project, I recently implemented a bespoke geometric multigrid solver in the ENDGame dynamical core for the Met Office Unified Model, which is expected to become operational soon. Together with *Dr. Markus Gross (Met Office)* I was able to demonstrate the superior performance of the multigrid solver (compared to the current BiCGStab solver) and our implementation has been successfully tested in operational configurations of the model.

Multilevel Monte Carlo methods in Atmospheric Modelling

The Met Office NAME Atmospheric Dispersion Model predicts the transport and spread of atmospheric pollutants by solving a stochastic (ordinary) differential equation (SDE) for a set of model particles. As the model is used for operational forecasts, such as the prediction of volcanic ash following the Icelandic eruptions in 2010 and 2011, it is vital to use the fastest possible numerical method. In the context of Ms. Sarah Cook's MPhil project we studied the performance gains which can be achieved by replacing the standard Monte Carlo integrator by the multilevel method in [Giles, 2008]. For this we implemented and applied the method for a set of realistic scenarios provided by the Met Office. The work was carried out in close collaboration with *Dr. David Thomson* and *Dr. Ben Devenish* at the Met Office. The new method shows potential to significantly increase the speed of predictions, in particular for tight error bounds.

I was invited to present the results of our work during a seminar talk at the University of Göttingen in November 2013.

Together with *Dr. Tony Shardlow (Bath)* I subsequently improved on the MLMC algorithm by studying more advanced time stepping scheme and cheaper stochastic sampling methods. Compared to a "standard" MLMC algorithm, these methods reduce the absolute cost of the method (i.e. the constant in front of the cost function), and hence beat standard Monte Carlo methods even at relatively loose error tolerances which are more relevant in practical applications. To test the algorithms numerically, I developed a modular C++ code and we were able to demonstrate significant performance gains for a set of test problems [14].

7 Open Software Development

Several research projects described in section 6 led to the development of software packages (implemented in high level languages such as C++, Fortran and Python) for testing the performance and scalability of the numerical methods. I believe that well designed and portable software is crucial to exploit future HPC systems. To allow reproducibility of results, I dedicated substantial effort to designing the code such that it is correct, fast and modular. To allow other researchers to benefit from my work and to facilitate cross-institutional collaboration, I made the source code available in public repositories on github and bitbucket under suitable open source licenses.

Tensor product multigrid solver for strongly anisotropic PDEs

[Fortran 90 code available at `https://bitbucket.org/em459/tensorproductmultigrid`]

Based on the tensor product idea in [Börm and Hiptmair, 1999] I implemented a parallel geometric solver algorithm for strongly anisotropic PDEs encountered in atmospheric modelling. The performance and scalability of the code has been tested on up to 65536 CPUs of the HECToR supercomputer [1].

Multi-GPU implementation of elliptic solvers for strongly anisotropic PDEs

[CUDA-C / C++ code available at `https://bitbucket.org/em459/ellipticsolvergpu`]

I also ported the above CPU version of the tensor product solver to multi-GPU clusters. For this I implemented both a Conjugate Gradient Krylov-subspace method and a geometric multigrid algorithm have CUDA-C kernels. The Generic Communication Library [Bianco, 2013] was used for inter-GPU communications. I showed that the code scales to up to 16384 GPUs of the Titan supercomputer [12].

Flexible Multilevel Monte Carlo integrators for the Langevin equation

[C++ code available at `https://bitbucket.org/em459/mlmclangevin`]

To test the performance of different time stepping- and stochastic sampling- methods in multilevel Monte Carlo algorithms, I developed a set of C++ classes for solving Langevin-type equations. Performance is achieved by extensive use of C++ templates. On the other hand the highly modular structure of the object oriented code makes it very easy to test different methods in a unified framework. Numerical results obtained with this code are reported in [14].

Performance portable Multigrid preconditioners for mixed discretisation of the Helmholtz equation

[Python / C code available at `https://github.com/firedrakeproject/firedrake-helmholtzsolver`]

I implemented a set of Python classes to solve a mixed finite element discretisation of the linearised Helmholtz equation in shallow water models. To allow performance portability, the code was implemented in the PyOP2/firedrake framework [Markall et al., 2013] and uses the well-tested PETSc library for iterative solver algorithms. My main contribution is the development of a matrix-free geometric multigrid preconditioner.

8 Publications

Over my career I have frequently published the results of my work in high-impact journals in the relevant fields and have increasingly taken over responsibility as a lead author. The results of my one-year diploma thesis project [8, 9] at the University of Bonn appeared in the European Physics Journal (2012 Impact factor: 5.247) and results from my PhD thesis [5, 4, 6, 7] were published in Physical Review D (2012 Impact factor 4.691) and Computer Physics Communications (2012 Impact factor 3.078). I also published the results of a research project carried out during my one-year exchange at the University of Edinburgh in Physical Review D [10]; publications at this early stage of the career are rare in physics.

Although the main focus of my work at the Met Office Atmospheric Dispersion Group (Nov 2009 - Aug 2011) was operational support and model development, I took the initiative and responsibility for publishing results on the OpenMP model parallelisation [3]. Since taking over a research role as a PostDoc at the University of Bath in September 2011 I published one article as a lead author [1] in the Quarterly Journal of the Royal Society (Impact factor 3.327) and submitted articles [12, 13] to Parallel Computing (Impact

Factor 1.214) and to the SIAM Journal on Scientific Computing (SISC, Impact factor 1.95). In both cases I took over the main responsibility for carrying out the research and preparing the manuscript for publication. I am co-author on a further article on multilevel Monte Carlo methods [14] which has just been submitted to Proceedings of the Royal Society A (5-year impact factor 2.241). Other results of my work as a PostDoc have appeared in peer-reviewed conference proceedings [2].

List of peer reviewed publications

[1] **Eike H. Müller**, Robert Scheichl. Massively parallel solvers for elliptic PDEs in Numerical Weather- and Climate Prediction. *to appear in Quarterly Journal of the Royal Meteorological Society*, 2014.

[2] **Eike H. Müller**, Xu Guo, Robert Scheichl, and Sinan Shi. Matrix-free GPU implementation of a preconditioned conjugate gradient solver for anisotropic elliptic PDEs. *to appear in Computation and Visualization in Science*, 2013.

[3] **Eike H. Müller**, Rupert Ford, Matthew C. Hort, Lois Huggett, Graham Riley, and David J. Thomson. Parallelisation of the Lagrangian atmospheric dispersion model NAME. *Computer Physics Communications*, 184(12):2734 – 2745, 2013.

[4] Eric B. Gregory, Christine T. H. Davies, Iain D. Kendall, Jonna Koponen, Kit Wong, Eduardo Follana, Elvira Gámiz, G. Peter Lepage, **Eike H. Müller**, Heechang Na, and Junko Shigemitsu. Precise B, B_s and B_c meson spectroscopy from full lattice QCD. *Phys. Rev. D*, 83:014506, Jan 2011.

[5] **Eike H. Müller**, A. Hart, and R. R. Horgan. Renormalization of heavy-light currents in moving nonrelativistic qcd. *Phys. Rev. D*, 83:034501, Feb 2011.

[6] A. Hart, G.M. von Hippel, R.R. Horgan, and **Eike H. Müller**. Automated generation of lattice QCD Feynman rules. *Computer Physics Communications*, 180(12):2698 – 2716, 2009.

[7] R. R. Horgan, L. Khomskii, S. Meinel, M. Wingate, K. M. Foley, G. P. Lepage, G. M. von Hippel, A. Hart, **Eike H. Müller**, C. T. H. Davies, A. Dougall, and K. Y. Wong. Moving nonrelativistic QCD for heavy-to-light form factors on the lattice. *Phys. Rev. D*, 80:074505, Oct 2009.

[8] B. Kubis, **Eike H. Müller**, J. Gasser, and M. Schmid. Aspects of radiative K^+_{e3} decays. *The European Physical Journal C*, 50(3):557–571, 2007.

[9] **Eike H. Müller**, B. Kubis, and U.-G. Meißner. T-odd correlations in radiative $K^+_{\ell 3}$ decays and chiral perturbation theory. *The European Physical Journal C - Particles and Fields*, 48(2):427–440, 2006.

[10] A. Hart and **Eike H. Müller**. Locality of the square-root method for improved staggered quarks. *Phys. Rev. D*, 70:057502, Sep 2004.

List of publications in conference proceedings

[11] **Eike H. Müller**, Christine T. H. Davies, Alistair Hart, Georg M. von Hippel, Ron R. Horgan, Iain Kendall, Andrew Lee, Stefan Meinel, Chris Monahan, and Matthew Wingate. Radiative corrections to the m(oving)NRQCD action and heavy-light operators. In *Proceedings of the XXVII International Symposium on Lattice Field Theory*, 2009.

Submitted Papers

[12] **Eike H. Müller**, Robert Scheichl, Benson Muite, Eero Vainikko. Petascale elliptic solvers for anisotropic PDEs on GPU clusters. Submitted to Parallel Computing, 2014. Available from: http://arxiv.org/abs/1402.3545.

[13] Andreas Dedner, **Eike H. Müller**, Robert Scheichl. Efficient multigrid preconditioners for anisotropic elliptic PDEs in geophysical modelling. Submitted to SIAM Journal on Scientific Computing (SISC), 2014. Available from: http://arxiv.org/abs/1408.2981.

[14] **Eike H. Müller**, Robert Scheichl, Tony Shardlow. Improving MLMC for SDEs with application to the Langevin equation. Submitted to Proceedings of the Royal Society A, 2014. Available from: http://arxiv.org/abs/1409.2342.

9 Awards and Scholarships

- *June 2013*: **Award for Best Presentation** Best talk at University of Bath HPC Symposium
- *September 2009*: **Oreste Piccioni Diploma** School of Subnuclear Physics, Erice, Sicily
- *September 2003 - July 2004*: **Scholarship holder of DAAD (German Academic Exchange Service)**[9] Highly competitive scholarship for funding a one year exchange at the University of Edinburgh
- *Autumn 2002 - Summer 2006*: **Scholarship holder of the Studienstiftung des Deutschen Volkes**[10] Highly competitive scholarship awarded to the top 0.5 percent of German University students

10 Grants and Computertime Allocations

Access to massively parallel national- and international high performance computing resources such as HECToR/ARCHER[11] and EMERALD[12] is usually awarded via a competitive application process which is similar to other grant applications. I was involved in the application and management of:

- *March 2013 - March 2014* **Computer time on EMERALD GPU Cluster** 7,800 GPU hours / 22800 CPU hours awarded on EMERALD, the UK's largest GPU cluster, over a period of sixth months (together with Prof. Rob Scheichl and Prof. Eero Vainikko).
- *September 2011 - April 2014* **Computer time on HECToR** 10 mio Allocation Units (worth approximately £58,000) awarded as part of the NERC allocation on the High-End Computing Terascale Resource (HECToR), the UK's largest supercomputing facility over a period of 2.5 years (together with Prof. Rob Scheichl and Dr. Stephen Pickles)
- *September 2011 - now* **Computer time on aquila** Resources on the Bath University Cluster. I was one of the first people using the GPU resources of the machine.

I wrote the application for the allocations on HECToR and EMERALD, completed the technical assessment and managed the grant and time allocation. This included frequent coordination with the operators of the machine and carrying out the parallel scaling runs.

[9] Deutscher Akademischer Austauschdienst, https://www.daad.org
[10] German National Academic Foundation, http://www.studienstiftung.de/en
[11] http://www.hector.ac.uk/, http://www.archer.ac.uk/
[12] http://www.einfrastructuresouth.ac.uk/cfi/emerald

Other grants

- *January 2013 - January 2016*: **Research Co-Investigator on NERC grant NE/K006754/1** Research grant worth £230,000 led by Prof. Rob Scheichl (PI) and Dr. Andreas Dedner (Co-Investigator)
- *August 2007* **University of Edinburgh Small Project Grant** Competitive student travel grant worth £1,000 for attending Summerschool on Lattice QCD and Applications, Seattle.

Unsuccessful applications

- *Jun 2013* **INCITE[13] grant** Co-investigator on highly competitive computer time application grant on US leadership computing facilities. PI: Dr. Benson Muite (KAUST/Tartu).

I contributed to the planning of the project and the writing of the proposal document. As a co-investigator I was responsible for the relevant sections on the development of massively parallel iterative solvers. I provided scaling data, wrote the work plan and made a case for the importance of the sub-project.

11 Talks and Presentations

Conferences

- June 2014: *"Petascale elliptic solvers on CPUs and GPUs with applications in geophysical modelling"* Invited talk at **8th International Workshop on Parallel Matrix Algorithms and Applications**, Lugano, Switzerland
- February 2014: *"Massively Parallel CPU and GPU Implementation of Elliptic Solvers in Geophysical Modelling"* Talk at **SIAM Conference on Parallel Processing in Scientific Computing**, Portland, Oregon
- December 2013: *"Matrix-free multi-GPU Implementation of elliptic solvers for strongly anisotropic PDEs"* Talk at **UK Manycore Developer Conference,**, University of Oxford
- June 2013: *"Algorithmic and Parallel Scalability of Elliptic Solvers in Atmospheric Modelling"* Talk at **Biannual Numerical Analysis Conference**, Glasgow
- June 2013: *"Fast and Scalable Elliptic Solvers for Anisotropic Problems in Geophysical Modelling"* Invited minisymposium talk at **MAFELAP Conference**, Brunel University, London
- April 2013: *"Fast and scalable Elliptic Solvers in Numerical Weather and Climate-Prediction on CPUs and GPUs"* Talk at **Exascale Applications and Software Conference (EASC)**, Edinburgh
- October 2012: *"Scalability of Elliptic solvers in numerical weather and climate-prediction"* Talk at **AMM satellite meeting on Weather and climate prediction on next generation supercomputers**, Met Office, Exeter
- October 2012: *"Scalability of Elliptic solvers in numerical weather and climate-prediction"* Invited talk at **15th ECMWF Workshop on High Performance Computing in Meteorology**, Reading
- August 2012: *"Scalability of Multigrid Solvers in Numerical Weather- and Climate- Prediction"* Talk at **European Multigrid Conference**, Schwetzingen
- July 2009: *"Radiative corrections to the m(oving)NRQCD action and heavy-light operators"* Talk at **The XXVII International Symposium on Lattice Field Theory**, Beijing

[13] Innovative and Novel Computational Impact on Theory and Experiment (INCITE), Oak Ridge Leadership Computing Facility http://www.doeleadershipcomputing.org/incite-program/

Invited seminar talks

- November 2013: *"Multilevel Monte Carlo Methods in Atmospheric Dispersion Modelling [and some ideas on applying MLMCMC to path integrals in Quantum Mechanics]"* **Oberseminar Particle Physics**, University of Göttingen
- May 2012: *"Scalability of Elliptic Solvers in Numerical Weather- and Climate- Prediction"* **Centre for Scientific Computing, University of Warwick**, University of Warwick
- October 2008: *"Rare B-decays on the lattice"* **Department of Physics**, University of Southampton
- October 2008: *"Rare B-decays on the lattice"* **Department of Physics**, University of Glasgow
- April 2008: *"Heavy-light form factors on the lattice: The rare decay $B \to K^*\gamma$"* **Institut für Strahlen- und Kernphysik**, University of Bonn

Talks at workshops and other meetings

- June 2014: *"Massively Parallel Scalability of Elliptic Solvers on Thousands of GPUs"* Talk at **Bath University HPC Symposium**, University of Bath
- January 2014: *"Petascale parallel solvers for extremely large elliptic PDEs on CPUs and GPUs"* Talk at **Bath/RAL NA day**, Rutherford Appleton Laboratory
- January 2014: *"Efficient multigrid solvers for strongly anisotropic PDEs in atmospheric modelling"* Invited talk at **CCP-ASEARch Multigrid study group**, STFC Daresbury Laboratory
- September 2013: *"Massively Parallel DUNE Implementation of Tensor-Product Multigrid Solvers in Geophysical Modelling"* Talk at **DUNE user meeting**, University of Aachen
- June 2013: *"GPU Implementation of Elliptic Solvers in Numerical Weather and Climate Prediction"* Talk at **Bath University HPC Symposium (prize for best presentation)**, University of Bath
- December 2012: *"Elliptic Solvers on GPUs"* Talk at **Isaac Newton Institute Programme on Multiscale Numerics for the Atmosphere and Ocean**, University of Cambridge
- September 2012: *"Massively Parallel Scaling Tests of Elliptic Solvers in NWP"* Talk at **Isaac Newton Institute Programme on Multiscale Numerics for the Atmosphere and Ocean**, University of Cambridge
- January 2012: *"Scalability of Iterative Solvers in Numerical Weather and Climate Prediction"* Talk at **Bath University HPC Symposium**, University of Bath

Internal seminar talks

- October 2013: *"Background on Probability: Convergence of random variables and Monte Carlo methods"* Talk at **Numerical Analysis seminar**, University of Bath
- October 2011: *"Parallelisation of the NAME Atmospheric Dispersion Model"* Talk at **Numerical Analysis seminar**, University of Bath

Posters

- June 2011: *"Parallelisation of the NAME Atmospheric Dispersion Model"* Poster at **CSC Summer School on High Performance Computing**, Espoo, Finland
- July 2010: *"The NAME Atmospheric Dispersion Model"* Poster at **Royal Meteorological Society Student Conference**, MetOffice, Exeter

12 Other Responsibilities

- *Sep 2012 - present:* **Organiser Numerical Analysis seminar**, University of Bath (together with Dr. Elisabeth Ullmann until 2nd semester 2013/14)
- *Jun 2013, Jun 2014:* **Scientific Organising Committee**, Bath HPC Symposium
- *Jan 2012, Apr 2012, Nov 2014:* **Organiser, GungHo! project meetings**
- *since 2012:* **Reviewer** for scientific journals and grant applications
  - Parallel Computing (1x)
  - NERC Research Grant Application (1x)
  - EPSRC "Software For the Future" Grant Application (1x)
  - Journal of Atmospheric and Oceanic Technology (1x)
  - Subreviewer, FVCA7 conference (1x) and SYNASC 2014 workshop (1x)
  - International Journal of Computer Mathematics (2x)

13 Nationality and Languages

- Nationality: German (EU citizen)
- Languages:
  - German (native speaker)
  - English (fluent, UK resident since September 2006)
  - Latin (basic knowledge)

Additional Literature relevant for this CV

[Bastian et al., 2008a] Bastian, P., Blatt, M., Dedner, A., Engwer, C., Klöfkorn, R., Kornhuber, R., Ohlberger, M., and Sander, O. (2008a). A generic grid interface for parallel and adaptive scientific computing. Part II: implementation and tests in DUNE. *Computing*, 82(2-3):121–138.

[Bastian et al., 2008b] Bastian, P., Blatt, M., Dedner, A., Engwer, C., Klöfkorn, R., Ohlberger, M., and Sander, O. (2008b). A generic grid interface for parallel and adaptive scientific computing. Part I: abstract framework. *Computing*, 82(2-3):103–119.

[Bianco, 2013] Bianco, M. (2013). An interface for halo exchange pattern. http://www.prace-ri.eu/IMG/pdf/wp86.pdf. Accessed: 11 Jan 2014.

[Börm and Hiptmair, 1999] Börm, S. and Hiptmair, R. (1999). Analysis of tensor product multigrid. *Numer. Algorithms*, 26:200–1.

[Falgout and Yang, 2002] Falgout, R. D. and Yang, U. M. (2002). hypre: a Library of High Performance Preconditioners. In Sloot, P., Tan, C., Dongarra, J., and Hoekstra, A., editors, *Lecture Notes in Computer Science*, volume 2331, pages 632–641. Springer.

[Giles, 2008] Giles, M. B. (2008). Multilevel monte carlo path simulation. *Operations Research*, 56(3):607–617.

[Markall et al., 2013] Markall, G. R., Rathgeber, F., Mitchell, L., Loriant, N., Bertolli, C., Ham, D. A., and Kelly, P. H. (2013). Performance-Portable Finite Element Assembly Using PyOP2 and FEniCS. In Kunkel, J. M., Ludwig, T., and Meuer, H. W., editors, *28th International Supercomputing Conference, ISC, Proceedings*, volume 7905 of *Lecture Notes in Computer Science*, pages 279–289. Springer.