PRISM - Rhodri B. Nelson: Summary of Activities

In this report I will present a brief summary of my activities over the past year whilst being funded by PRISM . The report will be separated into the following sections: Research and Software Development, Teaching and Supervision, Conference Presentations and Posters, and finally a List of Publications.

Research and software development

My primary role during the past year has been as a senior researcher and developer on the Devito project. Briefly, Devito is a domain specific language (DSL) [2] and compiler [3] for discretizing PDEs in the form of finite difference stencils and sparse operations (e.g. point wise interpolation). The API is built on top of `SymPy` and hence users can express systems of PDEs along with their boundary conditions in a symbolic form closely resembling the mathematics. The Devito compiler then takes this symbolic representation of a boundary value problem and translates it into a highly optimized, and if desired parallelised (SIMD, shared-memory, MPI), C kernel. Compilation is performed just-in-time for specific hardware at hand.

The primary target application of Devito has thus far been seismic imaging (inversion) problems. Devito 's design has therefore focused on satisfying the criteria for such a solver, which are discussed in [1]. My contributions to Devito over the past year have, as will be discussed below, covered a broad range of topics. One major landmark achieved in the past year has been full MPI coverage of the codebase. For this feature I designed and implemented the high-level MPI interface (allowing users to interact with distributed data arrays in a similar manner to traditional serial arrays) along with making significant contributions to the distributed grid functionality.

Another feature which has greatly matured over the past year is subdomains. Devito allows users to define subdomains (i.e. subsections) on a grid and specific equations, boundary conditions etc. on these subdomains. This feature allows, e.g. simple definitions of complex boundary conditions, multi-physics, and compute optimization. Along with further developing, maturing and providing tutorials regarding the usage of subdomains I have developed the `SubDomainSet` feature which allows the definition of an arbitrary large set of subdomains in a convenient and efficient manner.

Utilizing the `SubDomainSet` functionality in tandem with the custom FD stencil coefficient functionality (a feature I previously developed) I, along with my PhD student Edward Caunt, have also implemented immersed boundaries in Devito . This work was, as listed below, presented at the AGU 2019 fall meeting and OGPHC 2020 at Rice University.

To conclude, below is a non-exhaustive list of some of my other research and development activities over the past year:

- Development of the Devito viscoelastic kernel along with accompanying tutorials.

- Contributions to the development of GPU support and in particular the testing (CI) of GPU functionality.
- Moved aspects of our testing over to the Azure cloud which has halved the run time of our testing suite.
- Continued collaboration with researchers in the mathematics department at Imperial and at universities in Brazil on problems in fluid mechanics and conformal geometry.

Teaching and Supervision

Teaching and supervision activities are summarised below:

- Supervision of PhD student Edward Caunt.
- One of the lecturers on the ACSE7 MSc module.
- Supervision of MSc students completing their ACSE final projects.
- Interviewing prospective ACSE MSc students.

Conference Presentations, Workshops and Posters

- EAGE 2019, Spatially-optimized finite-difference schemes for numerical dispersion suppression in seismic applications, **Extended abstract and e-lightning presentation**, *Co-author*
- EAGE Middle-East 2019, Automated Distributed-memory Parallelism from Symbolic Specification in Devito, **Presentation**, *Presenter*
- AGU fall meeting 2019, Immersed Boundary Finite-Difference Methods for Seismic Wave Propagation Modelling: an Implementation Using Symbolic Computation in Devito. in seismic applications, **e-lightning presentation**, *Presenter*
- SIAM PP20, Automated Distributed-memory Parallelism from Symbolic Specification in Devito, **Presentation**, *Presenter*
- OGHPC 2020, From Zero to Devito, **Workshop**, *Presenter*
- OGHPC 2020, 3D immersed boundary generation from topography point clouds: an implementation in Devito, **Poster**, *Co-author*
- OGHPC 2020, Optimising Finite Difference Schemes Through Exploiting Sub-Domains in Devito, **Poster**, *Co-author*
- EAGE 2020, Generalised algorithm and implementation of topography within finite difference wave solvers, **Extended abstract and presentation**, *Co-author*

- M. Louboutin, F. Luporini, R. Nelson, P. Witte, G. Bisbas, J. Thorbecke, F. J. Herrmann & G. J. Gorman (2020), "Scaling through abstraction high-performance vectorial wave simulations for seismic inversion with Devito", *Supercomputing*, *Submitted*.
- R. B. Nelson, V. S. Krishnamurthy & D. G. Crowdy (2020), "Steadily rotating hollow vortex pairs", *Journal of Fluid Mechanics*, *Submitted*.
- T. Anselmo, B. Carneiro da Cunha, R. B. Nelson & D. G. Crowdy (2020) "Schwarz-Christoffel accessory parameter for quadrilaterals via isomonodromy", *Journal of Physics A: Mathematical and Theoretical*, *Accepted*.
- R. Weijermars, J. Wang & R. B. Nelson (2020) "Stress concentrations and failure modes in horizontal wells accounting for elastic anisotropy of shale formations", *Earth-Science Reviews*, v. 200, 102957. doi.org/10.1016/j.earscirev.2019.102957.

References

[1] Jean Virieux, Stphane Operto, Hafedh Ben-Hadj-Ali, Romain Brossier, Vincent Etienne, Florent Sourbier, Luc Giraud, and Azzam Haidar. Seismic wave modeling for seismic imaging. *The Leading Edge*, 28(5):538–544, 2009.

[2] M. Louboutin, M. Lange, F. Luporini, N. Kukreja, P. A. Witte, F. J. Herrmann, P. Velesko, and G. J. Gorman. Devito (v3.1.0): an embedded domain-specific language for finite differences and geophysical exploration. *Geoscientific Model Development*, 12(3):1165–1187, 2019.

[3] F. Luporini, M. Lange, M. Louboutin, N. Kukreja, J. Hückelheim, C. Yount, P. Witte, P. H. J. Kelly, G. J. Gorman, and F. J. Herrmann. Architecture and performance of devito, a system for automated stencil computation. *CoRR*, abs/1807.03032, jul 2018.