MIGRATE SHORT COURSE

Introductory GPU Computing for Fluid Dynamics Applications

Politecnico di Milano

October 3 – 5, 2018

Local Organizer: Prof. Aldo Frezzotti
Department of Aerospace Science and Technology
Politecnico di Milano

Lecturer: Dr. André Rigland Brodtkorb
Department of Informatics, University of Oslo
Department of Applied Mathematics, SINTEF ICT

Introductory GPU Computing for Fluid Dynamics Applications

GPUs (Graphic Processing Units) are emerging as a viable alternative to traditional high-performance computing architectures.
Their massively parallel architecture (thousands of cores, against the few of a traditional processor) allows, at least in principle, very high computing performance. On the other hand, the programming of GPUs, the development and / or transfer of codes developed on other platforms usually require a non negligible commitment and strongly dependent on the type of application.
The numerical solution of differential equations (ordinary and partial derivatives) is among applications that are better suited to transfer to GPU. In particular, the numerical solution of the compressible and incompressible fluid dynamics equations, at least in some formulations, is well suited to being efficiently carried on GPUs.
The aim of the course is to introduce the participants to the high performance calculation on GPU, with particular attention to the numerical solution of problems related to the dynamics of fluids and gases. The course will be developed over three consecutive days (3-5 October 2018), according to the attached program. Lectures and exercises will be held by Dr. André Brodtkorb (Oslo Metropolitan University) and Dr. Gian Pietro Ghiroldi (Camozzi Group Research Center - Brescia) whose curricula are attached to the present proposal. No specific prior knowledge is required, beyond the basic C / C ++ programming concepts. It is advisable each participant will have access to a laptop, particularly during tutorial and exercise classes. One of the following software installation options is suggested:

- CUDA and OpenCL on all machines. This requires installation of software on each computer, and the proper hardware (essentially an NVIDIA GPU). Further indications on request.
- CUDA in theory, OpenCL in practice. This requires installation of VirtualBox (https://www.virtualbox.org/) on everyones computer, to enable them to run a software image that has been prepared. This enables participants to try out OpenCL (which is very similar to CUDA) even in absence of a GPU.

Course Programme & Schedule

Wednesday, October 3rd 2018: Introduction to GPU computing (Lectures: 3h; Tutorials: 2h; Exercises: 2h)

- Motivation for GPU computing and applications
- GPU Architecture
- GPU Computing basics
- GPU programming languages
- GPU code development with CUDA and OpenCL in Python/C++
- Exercise: Computing PI with CUDA

Thursday, October 4th 2018: Advanced GPU Computing (Lectures: 3h; Tutorials: 2h; Exercises: 2h)

- Best practices for scientific software development (unit testing, floating point considerations, Git)
- Advanced GPU Architecture
- Local memory, warps, asynchronous execution etc.
- GPU profiling with CUDA and OpenCL
- Exercise: Parallel reductions in CUDA/OpenCL

Friday, October 5th 2018: Solving PDEs on GPUs (Lectures: 3h; Tutorials: 2h; Exercises: 2h)

- The heat equation, linear wave equation, Shallow water, Euler equations in CUDA/OpenCL.
- Exercise: Solving linear wave equation in CUDA/OpenCL
- Solving kinetic equations on GPU's: accelerating deterministic and Monte Carlo algorithms for the Boltzmann and BGK model kinetic equations.

Curriculum Vitae

October 26, 2016

André Rigland Brodtkorb, Ph.D., M.Sc., Age: 33
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Norwegian, English, some very basic German and French.

Employment

2010: Research scientist, Department of Applied Mathematics, SINTEF ICT, NO.
2014 (fall): Senior lecturer* (nor: Førstelektor), Department of Informatics, University of Oslo, NO.
2013 (fall): Senior lecturer* (nor: Førstelektor), Department of Informatics, University of Oslo, NO.
2010 – 2013: Associate professor* (nor: Førsteamanuensis), Norwegian School of Information Technology, NO.
2010 – 2010: Visiting researcher**, National Center for Computational Hydroscience and Engineering, US.
2007 – 2010: Advisor*, Department of Applied Mathematics, SINTEF ICT, NO.
2007 – 2007: Developer*, Norwegian Meteorological Institute, NO.

* Part time position. ** Three month research visit.

Education

2007 – 2010: Ph.D. from the University of Oslo, Department of Informatics.
Advisors: T. Dokken, K.-A. Lie, and K. M. Mørken.
Title: Scientific Computing on Heterogeneous Architectures [O3].
2002 – 2007: M.Sc. from the University of Oslo, Department of Informatics.
Advisors: K.-A. Lie and T. Hagen.
Title: A MATLAB Interface to the GPU [O4].

Relevant Experience

- Over thirteen peer reviewed articles, including eight in international journals.
- Cited over 400 times, h-index of 10, i10-index of 10[1].
- Over 35 lectures, talks and posters, including one keynote and five invited talks (see web page for details).
- Over 150.000 views of research videos published on Youtube.
- Rated 5.1 – 5.5 of 6 in student surveys as a skilled lecturer at the Norwegian School of Information Technology.
- Organizer of eVita Winter Schools (Research council project no. 203376) since 2011.
- Reviewer for several international journals.

2016: Guest lecturer for parallel computing course, University of Granada, Spain.
Project leader for several industry projects.
SINTEF representative at the University of Oslo career day both spring and fall.
Organizer of the Geilo Winter School in eScience on scientific visualization.
2015: Guest lecturer for parallel computing course, University of Granada, Spain.
News article on Equelle, a high-level programming language for finite volume methods.
Organizer of the Geilo Winter School in eScience on uncertainty quantification for physical phenomena.
2014: Opponent for Ph.D. thesis of Mattia Natali, "Sketch-based Modelling and Conceptual Visualization of Geomorphological Processes for Interactive Scientific Communication".
News article on EVITA webpages and in "Tilfeldig Gang" on Geilo Winter School.
Tutorial with Christian Schulz on using GPUs for optimization at VeRoLog 2014 conference.
Guest lecturer for parallel computing course, University of Granada, Spain.
Organizer of the Geilo Winter School in eScience on big data challenges to modern statistics.
2013: Guest lecturer for parallel computing course, University of Granada, Spain.
Invited Seminar on GPU-accelerated simulation, University of Granada, Spain.

[1] According to Google scholar

International Program Committee member for APMM 2013.
Contributor to "Setting the Default to Reproducible" (ICERM Workshop report), V. Stodden et al.
Organizer and lecturer at the Geilo Winter School in eScience on reproducible research.
Reviewer of "The CUDA Handbook: A Comprehensive Guide to GPU Programming", Addison-Wesley.

2012: News article on GPU-accelerated simulation in Computer Power User, USA.
Keynote at tsunami seminar, Universidad Tecnica Federico Santa María, Valparaíso, Chile.
Special session organizer for CMWR together with Wen-Mei Hwu, Univ. of Illinois at UC, USA.
TV appearance on Norwegian popular science program (Schrödingers katt).
Invited speaker on GPU-accelerated simulation FEniCS'12, Oslo, Norway.
Invited lecture on GPU computing, University of Bergen, Bergen, Norway.
News article on GPU-accelerated simulation in Materials World, United Kingdom.
Co-organizer of the Geilo Winter School in eScience on continuum mechanics.

2011: Work on GPU-accelerated simulation highlighted in "CUDA Spotlight".
Co-organizer of the Geilo Winter School in eScience on multiscale methods.

2010: Invited seminar on GPU computing, University of Mississippi, Oxford, Mississippi, USA.
Invited seminar on GPU-accelerated simulation, University of Mississippi, Oxford, Mississippi, USA.

2009: Guest lecturer for parallel computing course, University of Oslo, Norway.

2008: Guest lecturer for parallel computing course, University of Oslo, Norway.
Lecturer at the Second National Winter School in eScience on parallel computing, Geilo, Norway.

Supervision

2016: **Roman Bohne***, Conservation laws on GPUs. Joint with Knut-Andreas Lie.

2015: **Jens Kristoffer Reitan Markussen**, High-performance simulation on many-core computers. University of Oslo. Joint with Knut-Andreas Lie and Xing Cai. **Guro Seternes**, A GPU simulator for geologic storage of CO_2 using vertical numeric integration, Norwegian University of Science and Technology. Joint with Knut-Andreas Lie and Helge Holden.

2014 **Tor Garman Nærland**, High resolution conservation laws on many-core computers. University of Oslo. Joint with Knut-Andreas Lie and Knut M. Mørken. **Elisabeth Prestegård**, GPU accelerated simulation of CO_2 storage. Norwegian University of Science and Technology. Joint with Halvor Møll Nilsen and Helge Holden. **Gard Skevik**, Auto-tuning flood simulations on CPUs and GPUs. University of Oslo. Joint with Franz G. Fuchs and Martin Reimers. **Gorm Skevik**, Load-balancing techniques for multi-GPU flood simulations. University of Oslo. Joint with Franz G. Fuchs and Martin Reimers. **André Amundsen**, Auto-tuning techniques for Flood Simulations on the GPU. University of Oslo. Joint with Franz G. Fuchs and Martin Reimers.

2013: **Espen Graff Berglie**. High-Order Schemes for the Shallow Water Equations on GPUs. Norwegian University of Science and Technology. Joint with Knut-Andreas Lie and Helge Holden.

* In progress.

Journal Papers[2]

[J1] M.L. Sætra, **A.R. Brodtkorb**, and K.-A. Lie. Efficient GPU-implementation of adaptive mesh refinement for the shallow-water equations. *Journal of Scientific Computing*, 2014.

[J2] **A.R. Brodtkorb**, T.R. Hagen, C. Schulz, and G. Hasle. GPU computing in discrete optimization part i: Introduction to the GPU. *EURO Journal on Transportation and Logistics*, 2:129–157, 2013.

[J3] C. Schulz, G. Hasle, **A.R. Brodtkorb**, and T.R. Hagen. GPU computing in discrete optimization part ii: Survey focused on routing problems. *EURO Journal on Transportation and Logistics*, 2:159–186, 2013.

[J4] **A.R. Brodtkorb**, M.L. Sætra, and T.R. Hagen. GPU programming strategies and trends in GPU computing. *Journal of Parallel and Distributed Computing*, 73:4–13, 2012.

[J5] **A.R. Brodtkorb**, T.R. Hagen, K.-A. Lie, and J. Natvig. Simulation and visualization of the Saint-Venant system using GPUs. *Computing and Visualization in Science*, 13(7):1–13, 2011.

[J6] **A.R. Brodtkorb**, M.L. Sætra, and M. Altinakar. Efficient shallow water simulations on GPUs: Implementation, visualization, verification, and validation. *Computers & Fuids*, 55:1–12, 2011.

[J7] **A.R. Brodtkorb**, C. Dyken, T.R. Hagen, J.M. Hjelmervik, and O. Storaasli. State-of-the-art in heterogeneous computing. *Scientific Programming*, 18(1):1 – 33, May 2010.

[2] Preprints of publications are available from http://babrodtk.at.ifi.uio.no/

[J8] **A.R. Brodtkorb**. An asynchronous API for numerical linear algebra. *Scalable Computing: Practice and Experience*, 9(3):153–163, 2008.

Conference Papers

[C1] T. Gierlinger, **A.R. Brodtkorb**, A. Stumpf, M. Weilera, and F. Michel. Visualization of marine sand dune displacements utilizing modern GPU techniques. In *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 2015.

[C2] T.A. Haufmann, A. Berge, **A.R. Brodtkorb**, K. Kaspersen, and A. Kim. Real-time online camera synchronization for volume carving on GPU. In *IEEE International Conference on Advanced Video and Signal-Based Surveillance (AVSS)*, 2013.

[C3] **A.R. Brodtkorb** and M.L. Sætra. Explicit shallow water simulations on GPUs: Guidelines and best practices. In *Proceedings of the XIX International Conference on Computational Methods for Water Resources*, 2012.

[C4] M.L. Sætra and **A.R. Brodtkorb**. Shallow water simulations on multiple GPUs. In *Proceedings of the Para 2010 Conference*, pages 56–66, . Springer Berlin / Heidelberg, 2011.

[C5] **A.R. Brodtkorb** and T.R. Hagen. A comparison of three commodity-level parallel architectures: Multi-core CPU, the Cell BE and the GPU. In *Mathematical Methods for Curves and Surfaces*, pages 70–80, . Springer Berlin / Heidelberg, February 2010.

[C6] **A.R. Brodtkorb**. The graphics processor as a mathematical coprocessor in matlab. In *Complex, Intelligent and Software Intensive Systems, International Conference*, volume 0, pages 822–827, Los Alamitos, CA, USA, 2008. IEEE Computer Society.

Other Publications

[O1] A. Berge, **A.R. Brodtkorb**, T.A. Haufmann, K. Kaspersen, and A. Kim. Recommendations and guidelines for image processing on heterogenous hardware. Technical report, EU FP7 project ADABTS, 2013.

[O2] **A.R. Brodtkorb**, T.R. Hagen, and L.P. Røed. One-layer shallow water models on the GPU. Technical report 27, Norwegian Meteorological Institute Oslo, 2013.

[O3] **A.R. Brodtkorb**. *Scientific Computing on Heterogeneous Architectures*. PhD thesis, University of Oslo, 2010. ISSN. 1501-7710, No. 1031.

[O4] **A.R. Brodtkorb**. A MATLAB interface to the GPU. Master's thesis, University of Oslo, 2007.

[O5] **A.R. Brodtkorb**, T. Fladby, and M.L. Sætra. PLU factorization on a cluster of GPUs using fast ethernet. [technical report], 2007.

[O6] **A.R. Brodtkorb**. Matrix-matrix multiplication in MATLAB using the GPU. [technical report], 2006.