SciDAC Visualization and Analytics Center for Enabling Technologies

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UC Davis Final Report

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Summary

The purpose of the SciDAC Visualization and Analytics Center for Enabling Technologies (VACET) focused on leveraging scientific visualization and analytics software technology as an enabling technology for increasing scientific productivity and insight. The vision for VACET was to adapt, extend, create (when necessary) and deploy visualization and data understanding technologies for our science stakeholders. UC Davis was a significant part of this effort, working directly with science stake-holders to motivate the discovery and creation of new visualization and analytics technologies, which are addressed by our team.

This document reports the accomplishments of the UC Davis component of VACET. In short, we have developed significant advances in the visualization of flow, the application of statistical methods to visualization, the integration of visualization methods into problem-solving methodologies for science, and the parallelization of these methods. The grant supported several graduate students, postdocs, professional researchers and undergraduates, a number of which have taken positions at the National Laboratories.

State-of-the-art computational science simulations generate large-scale vector field datasets. Visualization and analysis are key aspects of obtaining insight into these datasets and represent an important challenge. The VACET Center enabled the discovery and development of a number of innovative visualization and analysis techniques at UC Davis that, because of our collaborative methods with national laboratory researchers and our science stakeholders, could not have been accomplished otherwise.

Personnel

The UC Davis component of the SciDAC II Visualization and Analytic Center for Enabling Technologies (VACET) has supported a number of faculty, postdoc and student researchers over the course of the grant. Notably, the project supported

- Kenneth I. Joy, a faculty member in the Computer Science Department and the VACET/UC Davis site PI, through summer salary.
- Christoph Garth, postdoc, now a faculty member at Kaiserslautern University in Germany. Garth won the 2011 UC Davis award for the outstanding postdoc at the University.
- Eduard Deines, postdoc, now working for cd-Adapco in Austin TX
- Harald Obermaier, postdoc, now working for Apple
- Hank Childs, serving a shared position between UC Davis and Lawrence Berkeley National Laboratory. Now a faculty member at the University of Oregon and researcher at Lawrence Berkeley National Laboratory. Hank has subsequently won a DoE Career Award.
- Harinan Krishnan, graduate student. Now working at Lawrence Berkeley National Laboratory.
- David Camp, graduate student. Now working at Lawrence Berkeley National Laboratory
- Kevin Bensema, graduate student. Graduating June, 2016. Working summers with Pacific Northwest National Laboratory
- Jennifer Chandler, graduate student. Jennifer was also supported through an NSF Fellowship.
- Iuri Prilepov, graduate student. Iuri received his Master's Degree in 2013 and is currently working at Google.
- Alex Agranovsky, graduate student
- Luke Gosink, graduate student. Received a Ph.D. in 2009 and now works for Pacific Northwest National Laboratory

Projects

Streamlines

This effort has accomplished the initial goal of implementing and deploying a parallel capable streamline infrastructure with several different user definable parallelization strategies. This work resulted in several publications and was implemented through a new advection-based method that was inserted into the VisIt visualization package. We implemented a streamline integration method for block-structured AMR data, developed new methods for pathline, pathsurface, stream surface, time surface, and streak surface methods. All of these methods were integrated into VisIt and is now available to researchers throughout the National Laboratories.

Parallelization

We completed design and implementation of several hybrid parallelization algorithms focused on advection-based visualization algorithms, being the first group to attempt to integrate these methods into a large-scale parallel environment. We have also developed new methods that focus on using interpolation of short streamlines/pathlines as a replacement for the time-consuming advection methods necessary in current techniques. These methods look very promising.

Lagrangian Techniques

The mathematical interpretation of integral curves as the solutions of ordinary differential equations coincides with that of massless point particles that are advected along the vector field. The Lagrangian view examines the evolution from the point of view of an observer attached to a particle moving with the vector field. While both approaches are technically on equal footing, the Lagrangian perspective allows a more natural and intuitive description and analysis of the overall behavior. We have developed integral-curve methods that support Lagrangian techniques and have adapted them to parallel systems.

Multi-temporal Visualization of Scalar and Vector Fields

A significant contribution of VACET researchers is the development of methods beyond that of the “streamline” to those of “integral curves”, which can be used for a base to enable a number of vector-field visualization methods. These methods include the generation of path lines, streak lines, and time lines, as well as their surface equivalents, path surfaces, streak surfaces and time surfaces. We were able to expand these methods to show the end user summary statistics over time. These multi-temporal techniques will be very valuable in ensemble methods.

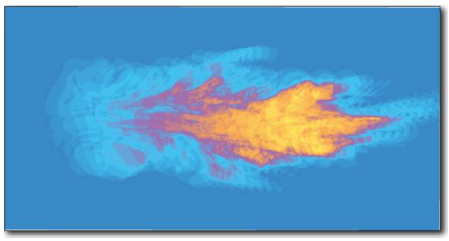

Figure 1: Multi-temporal visualization with a flow example

Material Interfaces

Many important classes of computer simulations of physical phenomena require support for “materials,” i.e. discrete regions of space with different physical properties. For example, a simulation of tidal waves needs to partition space into water and air, and a simulation of an automobile accident must model glass, metal, and rubber. We have developed new methods of determine boundaries in materials, given data sets based upon “volume fractions.”

These are difficult problems as there are multiple “correct” solutions and many criteria for a good reconstruction: Does it honor the volume fractions? Does it place materials from neighboring cells next to each other? Does it create large discontinuities? Although simulations reconstruct interfaces themselves, their primary concern is advecting materials through the mesh correctly, not visualization and analysis. Their reconstructions often lead to inaccurate analysis and poor aesthetics.

Statistical Methods

We have been working with researchers from Lawrence Berkeley National Laboratory and Pacific Northwest National Laboratory to develop new methods of visualization based upon statistics quantities. These methods have been used to develop methods for visualizing correlations between variables in multi-dimensional data analysis methods, and to assist the analysis of ensemble methods.

Publications

[1] Alexy Agranovsky, Harald Obermaier, and Kenneth I. Joy, "A Framework for the Visualization of Finite-Time Continuum Mechanics Effects in Time-Varying Flow," 9th International Symposium on Visual Computing (ISVC), Lecture Notes in Computer Science, Vol 8034, 349-360, 2013

[2] Jennifer Chandler, Harald Obermaier, and Kenneth I. Joy. "Illustrative Rendering of Particle Systems," Proceedings of Vision, Modeling, and Visualization (VMV 2013), pp. 177-185.

[3] Luke Gosink, Kevin Bensema, T. Pulsipher, Harald Obermaier, M. Henry, Hank Childs, and Kenneth I. Joy, "Characterizing and Visualizing Predictive Uncertainty in Numerical Ensembles Through Bayesian Model Averaging," *IEEE Transactions on Visualization and Computer Graphics*, (Proceedings of IEEE Visualization 2013), vol. 19, no. 12, December 2013, 2703-2712.

[4] Mathias Hummel, Harald Obermaier, Christoph Garth, and Kenneth I. Joy, "Comparative Visual Analysis of Lagrangian Transport in CFD Ensembles," *IEEE Transactions on Visualization and Computer Graphics*, (Proceedings of IEEE Visualization 2013)), vol. 19, no. 12, December 2013, 2743-2752. [**Best Paper**]

[5] David Camp, Harinarayan Krishnan, David Pugmire, Christoph Garth, E. Wes Bethel, Kenneth I. Joy, Hank Childs and Ian Johnson, "GPU Acceleration of Particle Advection Workloads in a Parallel, Distributed Memory Setting," Proceedings of the Eurographics Symposium on Parallel Graphics and Visualization (EGPGV) 2013, Girona, Catalonia, Spain, 1-8

[6] Sohail Shafii, Harald Obermaier, V. Kolar, Mario Hlawitschka, Christoph Garth, Bernd Hamann, and Kenneth I. Joy, "Illustrative Rendering of Vortex Cores," In Eurographics Conference on Visualization (EuroVis 2013) - Short Papers, 61-65.

[7] Harald Obermaier, and Kenneth I. Joy, "Local Data Models for Probabilistic Transfer Function Design," In Eurographics Conference on Visualization (EuroVis 2013) - Short Papers, 43-47.

[8] Iuri Prilepov, Harald Obermaier, Eduard Deines, Christoph Garth, and Kenneth I. Joy, "Cubic Gradient-Based Material Interfaces," *IEEE Transactions on Visualization and Computer Graphics*, vol. 19, No. 10, October 2013, 1687-1699

[9] Sohail Shafii, Harald Obermaier, R. Linn, E. Koo, Mario Hlawitschka, Christoph Garth, Bernd Hamann, and Kenneth I. Joy, "Visualization and Analysis of Vortex-Turbine Intersections in Wind Farms," *IEEE Transactions on Visualization and Computer Graphics*, vol. 19, no. 9, pp. 1579-1591, 2013.

[10] Sohail Shafii, Harald Obermaier, Bernd Hamann and Kenneth I. Joy, Topological Features in Glyph-Based Corotation Visualization, 5th Workshop on Topological Methods in Data Analysis and Visualization (TopoInVis 2013).

[11] Lars Huettenberger, Harald Obermaier, Christoph Garth, Kenneth I. Joy and Hans Hagen, "Topological Aspects of Material Interface Reconstruction: Challenges and Perspectives," 5th Workshop on Topological Methods in Data Analysis and Visualization (TopoInVis 2013).

[12] Matthew J. O'Brien, Patrick S. Brantley, Ken I. Joy, "Scalable Load Balancing for Massively Parallel Distributed Monte Carlo Particle Transport", Proceedings of the International Conference on Mathematics & Computational Methods Applied to Nuclear
Science & Engineering, Sun Valley, ID, 2013.

2012:

[13] E. Wes Bethel, David Camp, Hank Childs, Christoph Garth, Mark Howison, Kenneth I. Joy and David Pugmire, "Hybrid Parallelism" in High Performance Visualization---Enabling Extreme-Scale Scientific Insight, E.W. Bethel, H. Childs, and C. Hansen, eds., 2012, 261-290

[14] David Camp, Hank Childs, Christoph Garth, Dave Pugmire and Kenneth I. Joy, "Parallel Stream Surface Computation for Large Data Sets," Proceedings of the IEEE Symposium on Large-Scale Data Anaysis and Visualization (LDAV), Seattle WA, USA, 2012, 39-47

[15] Hari Krishnan, Christoph Garth, Jens Guhring, M. Akif Gulsun, Andreas Greiser, and Kenneth I. Joy, "Analysis of Time-Dependent Flow-Sensitive PC-MRI Data," *IEEE Transactions on Visualization and Computer Graphics,* Vol. 18, No. 6, June 2012, 966-977

[16] Harald Obermaier, Fang Chen, Hans Hagen and Kenneth I. Joy, "Visualization of Material Interface Stability," Proceedings of Pacific Visualization Conference, Songdo, Korea, 2012, 225-232

[17] Harald Obermaier and Kenneth I. Joy, "Derived Metric Tensors for Flow Surface Visualization," *IEEE Transactions on Visualization and Computer Graphics*, Vol. 18, No. 12, December 2012, 2149-2158.

[18] Harald Obermaier and Kenneth I. Joy, "Function Field Analysis for the Visualization of Flow Similiarity in Time-Varying Vector Fields," Proceedings of the International Symposium on Visual Computing, Rethymnon, Crete, Greece, 2012, In Advances in Visual Computing, volume 7432 of Lecture Notes in Computer Science, pages 253–264. Springer Berlin Heidelberg.

[19] Harald Obermaier, Magali I. Billen, Kenneth I. Joy, Hans Hagen and Martin Hering-Bertram, "Visualization and Multivariate Clustering of Scattered Moment Tensors," *Information Visualization*, Vol. 11, No. 1, January 2012, 43-59.

[20] Simon Schoreder, John A. Peterson, Harald Obermaier, Louise H. Kellogg, Kenneth I. Joy and Hans Hagen, "Visualization of Flow Behavior in Earth Mantle Convection," *IEEE Transactions on Visualization and Computer Graphics*, 2012, Vol. 18, No. 12, December 2012, 2198-2207

2011:

[21] Alexy Agranovsky, Christoph Garth and Kenneth I. Joy, "Extracting Flow Structures Using Sparse Particles," Proceedings of the Vision, Modeling and Visualization Workshop, 2011, Berlin Germany, 153-160.

[22] David Camp, Hank Childs, Amit Chourasia, Christoph Garth and Kenneth I. Joy, "Evaluating the Benefits of An Extended Memory Hierarchy for Parallel Streamline Algorithms," Proceedings of the IEEE Symposium on Large-Scale Data Anaysis and Visualization, Providence, RI, USA, 2011, 57-64

[23] David Camp, Christoph Garth, Hank Childs, Dave Pugmire and Kenneth I. Joy, "Streamline Integration Using MPI-Hybrid Parallelism on a Large Multicore Architecture," *IEEE Tranactions on Visualization and Computer Graphics,* Vol. 17, No. 11, November 2011, 1702-1713.

[24] Luke Gosink, Christoph Garth, John Anderson, E. Wes Bethel, and Kenneth I. Joy, "An Application of Multivariate Statistical Analysis for Query-Driven Visualization," *IEEE Transactions on Visualization and Computer Graphics*, Vol. 17, No. 3, 2011, 264--275.

[25] Matthias Hummel, Christoph Garth, Bernd Hamann, Hans Hagen, Kenneth I. Joy, "Illustrative Visualization of a Vortex Breakdown Bubble," *Computer Graphics Forum*, Vol 30, No. 1, 2011, 235-236

[26] Xavier Tricoche, Christoph Garth, Alan Sanderson and Kenneth I. Joy, "Visualizing Invariant Manifolds in Area-Preserving Maps," Proceedings of TopoInVis 2011, Zurich, Switzerland, 2011

2010:

[27] John Anderson, Christoph Garth, Mark A. Duchaineau, and Kenneth I. Joy, "Smooth, Volume-Accurate Material Interface Reconstruction," *IEEE Transactions on Visualization and Computer Graphics,* Vol. 16, No. 5, 2010, 802-814.

[28] David Camp, Christoph Garth, Hank Childs, David Pugmire, and Kenneth I. Joy, "Streamline Integration using MPI-Hybrid Parallelism on Large Multi-Core Architectures," *IEEE Transactions on Visualization and Computer Graphics,* 17 (11), 1702-1713

[29] Hank Childs, Sean Ahern, Jeremy Meredith, Mark Miller and Kenneth I. Joy, "Comparative Visualization using Cross-Mesh Field Evaluation and Derived Quantities," in H. Hagen, ed., Scientific Visualization, Schloss Dagstuhl – Leibnitz

Center for Informatics, Vol 2, 2010.

[30] Christopher Co, Mark A. Duchaineau and Kenneth I. Joy, “Streaming Aerial Video Textures,” in H. Hagen, ed., Scientific Visualization: Advanced Concepts, Schloss Dagstuhl – Leibniz Center for Informatics, Vol 1, 2010.

[31] Eduard Deines, Gunther Weber, Christoph Garth, Brian Van Straalen, Sergey Borovikov, Daniel F. Martin and Kenneth I. Joy, “On the Computation of Integral Curves in Adaptive Mesh Refinement Vector Fields,” in H. Hagen, ed., Scientific Visualization, Schloss Dagstuhl – Leibnitz Center for Informatics, Vol. 2, 2010

[32] Christoph Garth and Kenneth I. Joy, “Fast, Memory-Efficient Cell Location in Unstructured Grids for Visualization,” *IEEE Transactions on Visualization and Computer Graphics* (Proceedings of IEEE Visualization 2010), Vol. 16, No. 6, October 2010, 1541-1550.

[33] Christoph Garth, Hari Krishnan and Kenneth I. Joy, “Advanced Vector Field Analysis using Integral Curve Techniques,” In Journal of Physics Conference Series, Proceedings of SciDAC 2010

[34] Mattias Hummel, Christoph Garth, Bernd Hamann, Hans Hagen, and Kenneth I. Joy, “IRIS: Illustrative Rendering of Integral Surfaces”, IEEE Transactions on Visualization and Computer Graphics, (Proceedings of IEEE Visualization 2010), Vol 16, No. 6, October 2010, 1319 - 1328

[35] G. H. Weber, S. Ahern, E.W. Bethel, S. Borovikov, H.R. Childs, E. Deines, C. Garth, H. Hagen, B. Hamann, K.I. Joy, D. Martin, J. Meredith, Prabhat, D. Pugmire, O. Rübel, B. Van Straalen and K. Wu. "Recent Advances in VisIt: AMR Streamlines and Query-Driven Visualization." In:Numerical Modeling of Space Plasma Flows: Astronum-2009 (Astronomical Society of the Pacific Conference Series). 2010.

2009:

[36] John Anderson, Christoph Garth, Mark A. Duchaineau, and Kenneth I. Joy, “Interactive Visualization of Function Fields by Range-Space Segmentation,” Proceedings of EuroVis 2009, *Computer Graphics Forum*, Vol. 28, No. 3, 727-734.

[37] E. W. Bethel, C. Johnson, S. Ahern, J. Bell, P.-T. Bremer, H. Childs, E. Cormier-Michel, M. Day, E. Deines, T. Fogal, C. Garth, C. G. R. Geddes, H. Hagen, B. Hamann, C. Hansen, J. Jacobsen, K. Joy, J. Krüger, J. Meredith, P. Messmer, G. Ostrouchov, V. Pascucci, K. Potter, Prabhat, D. Pugmire, O. Rübel, A. Sanderson, C. Silva, D. Ushizima, G. Weber, B. Whitlock, K. Wu. "Occam's Razor and Petascale Visual Data Analysis." In Journal of Physics Conference Series, Proceedings of SciDAC 2009

[38] Brian Budge, Tony Bernadin, Jeff Stuart, Kenneth I. Joy and John Owens, “Out-of-core Data Management for Path Tracing on Hybrid Resources,” Proceedings of EuroGraphics 2009, *Computer Graphics Forum*, Vol. 28, No. 2, April 2009, 385-396.

[39] Christoph Garth, Eduard Deines, Kenneth Joy, Hank Childs, Gunther H. Weber, E. Wes Bethel, Sean Ahern, David Pugmire, Chris Johnson, "Twists and Turns:Vector Field Visual Data Analysis for Petascale Computational Science", in "SciDAC Review", Number 15, pp 10--21, 2009

[40] Luke Gosink, Kesheng Wu, Wes Bethel, John Owens and Kenneth I. Joy, "Data Parallel Bin-Based Indexing for Answering Queries on Multi-Core Architectures," Proceedings of the 21st Annual Conference on Scientific and Statistical Database Management, New Orleans, LA, June 2009, Vol. 5566, Springer-Verlag, Berlin, 110-129.

[41] Hari Krishnan, Christoph Garth and Kenneth I. Joy, "Time and Streak Surfaces for Flow Visualization in Large Time-Varying Data Sets," *IEEE Transactions on Visualization and Computer Graphics,* (Proceedings of IEEE Visualization 2009), Vol. 15, No. 6, October, 2009, 1267-1274.

2008:

[42] John Anderson, Christoph Garth, Mark A. Duchaineau and Kenneth I. Joy, "Discrete Multi-Material Interface Reconstruction for Volume Fraction Data," Proceedings of the European Visualization Conference, *Computer Graphics Forum*, Vol. 27, No. 3, 2008, 1015-1022.

[43] Janine Bennett, Valerio Pascucci, and Kenneth Joy, "A genus oblivious approach to cross parameterization," *Computer Aided Geometric Design*, 45(8), 2008, 592-606.

[44] E. Wes Bethel, Chris Johnson, Charles Hansen, Claudio Silva, Steve Parker, Alan Sanderson, L. Myers, M. Code, Xavier Tricoche, Sean Ahern, George Ostrouchov, David Pugmire, J. Daniel, Jeremy Meredith, Valerio Pacucci, Hank childs, Peer-Timo Bremer, A. Mascarenhas, Keneth I. Joy, Bernd Hamann, Christoph Garth, C. Aragon, Gunther Weber, Prabat, "Seeing the Unseeable," SciDAC Review, No. 8, 2008, 24-33.

[45] Louis Feng, Ingrid Hotz, Bernd Hamann, and Kenneth I. Joy, "Anisotropic Noise Samples," IEEE Transactions on Visualization and Computer Graphics, 14(2), pp. 342-354, March/April, 2008.

[46] Louis Feng, Ingrid Hotz, Bernd Hamann, Kenneth Joy, "Dense Glyph Sampling for Visualization," in: Laidlaw, D.H. and Weickert, J., eds., Visualization and Processing of Tensor Fields: Advances and Perspectives, SpringerVerlag, Heidelberg, Germany, 177-196

[47] Christoph Garth, Xavier Trichoche, Kenneth I. Joy and Gerik Scheuermann, "Lagrangian Visualization of Flow-Embedded Surface Structures," Proceedings of the European Visualization Conference, *Computer Graphics Forum*, Vol. 27, No. 3, 2008, 767-774.

[48] Christoph Garth, Harinan Krishnan, Xavier Tricoche, Thomas Bobach and Kenneth I. Joy, "Generation of Accurate Integral Surfaces in Time-Dependent Vector Fields."

IEEE Transactions on Visualization and Computer Graphics, (Proceedings of IEEE Visualization 2008), Vol. 14, No. 6, October 2008, 1404-1411.

[49] Christoph Garth, Xavier Tricoche, Alexander Wiebel and Kenneth I. Joy, "On the Role of Domain-specific Knowledge in the Visualization of Technical Flows.", Proceedings of Simulation and Visualization 2008, 107-120.

[50] Luke Gosink, John C. Anderson, E. Wes. Bethel, and Kenneth I. Joy. "Query-Driven Visualization of Time-varying Adaptive Mesh Refinement Data." *IEEE Transactions on Visualization and Computer Graphics*, (Proceedings of IEEE Visualization 2008), Vol. 14, No. 6, 1715-1722.