VISUALIZATION AND QUANTIFICATION OF EVOLVING DATASETS

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For a full discussion of the research resulting from this grant please see our web site: http://www.caip.rutgers.edu/vizlab.html and the publications accompanying this report.

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INTRODUCTION

The material below is the final technical/progress report of the Laboratory for Visiometrics and Modeling (Vizlab) in visiometrics for the grant entitled *Visualization and Quantification of Evolving Phenomena.* This includes coordination with DOE supported scientists at Los Alamos National Laboratory (LANL) and Princeton Plasma Physics Laboratory (PPPL), and with theoretical and computational physicists at the National Institute of Fusion Science (NIFS) in Nagoya, Japan and the Institute of Laser Engineering (ILE) in Osaka, Japan. Our research areas included:

- Enhancement and distribution of the DAVID environment, this is a 2D visualization environment incorporating many advanced quantifications and diagnostics useful for prediction, understanding, and reduced model formation;
- Feature extraction, tracking and quantification of 3D time-dependent datasets of non-linear and turbulent simulations both compressible and incompressible. This work is applicable to all 3D time-varying simulations.
- Visiometrics in shock-interface interactions and mixing for the Richtmyer-Meshkov (RM) environment. This work highlights reduced models for nonlinear evolutions and the role of density stratified interfaces (contact discontinuities) and has application to supernova physics, laser fusion and supersonic combustion.

The collaborative projects included areas of:

1. Feature extraction, tracking and quantification in 3D turbulence: compressible and incompressible;
2. Numerical Tokamak Project (NTP);
3. Data projection and reduced modeling fpr shock-interface interactions and mixing. (The Richtmyer-Meshkov (RM) environment relevant to laser fusion and combustion).

ACCOMPLISHMENTS IN VISIOMETRICS

DAVID Environment

DAVID is an interactive, programmable environment that allows the user to interact with two dimensional (2D) numerical data [2]. The datasets can represent any kind of scalar fields: pressure, charge, density, temperature etc. Multiple datasets are allowed to represent time or space series. The essence of the method is to render different colors in the 2D image to different ranges of the datasets. Particular value ranges (e.g. high or low) can be isolated and defined as coherent structures or objects with this procedure. As opposed to most standard visualization environments, DAVID facilitates the visiometric process, namely extraction, tracking, quantification and mathematization of evolving and interacting amorphous coherent structures from complex data sets. This allows the scientist to measure observed quantities and extract meaningful quantities from the dataset to help form reduced models of the original set of equations or improve existing predictive formulations. DAVID's new visiometric features include color-map adjustment, skeleton extraction and quantification via slope and curvature, two function juxtaposition, and two-variable distribution functions (linked to original functions.) Examples of these functions and the entire manual is given on our web site.

Visualization and Feature Extraction on the Numerical Tokamak Datasets:

We have continued to implement our 3D visiometric routines for the numerical (gyrokinetic) Tokamak simulation datasets provided by Scott Parker of PPPL. A movie was made to highlight the creation of coherent structures from a time series calculations. The coherent structures were highlighted using isosurfaces and slices. The volume features were also extracted using a segmentation technique adapted to irregular periodic grids. This algorithm is described in [1]. Once extracted, these features can be quantified and tracked [3].

Feature Tracking

Large 3D time-varying datasets (e.g. 512^3, with 1000 time steps) are difficult to visualize and analyze. This is especially true for turbulent datasets in which there are many amorphous evolving features. Searching through hundreds (possibly thousands) of large 3D scalar and vector datasets for particular events and features where each data set can contain many amorphous structures (sometimes up to 1000 or more) is impractical. Automatic feature extraction and tracking can aid in this process by highlighting the features as they evolve.

We have designed and implemented a full 3D volume tracking program [6, 7, 4]. Features are extracted from the first dataset and then matched in subsequent datasets. All features are tracked, as well as the mass, moment and volume change of the features. The tracker detects five different *events*: continuation, dissipation, bifurcation, amalgamation, and creation. Bifurcation is where a feature in one dataset splits into more than one feature in the next dataset, and amalgamation is when two or more features merge. The algorithm performs a full volume comparison, and only checks for amalgamation and bifurcation with overlapping regions. An octree is used for efficiency and quantification calculation. Because full volume comparisons are done , many of the problems in the previous implementation (based upon maxima tracking) have been resolved. This technique is very powerful and has been shown effective for visualizing and analyzing large turbulent datasets [5, 8].

Visiometrics in the RM Environment

Planar shocks in fluids deposit vorticity in a variable density region because of the misalignment of the pressure and density gradients. This phenomenon assumes particular importance in shock induced mixing (shocks moving through fuel bubbles, depositing circulation on the interface) and supernovae (very strong shocks moving through stellar atmospheres).

To study the phenomenon, we subjected a vertical interface between 2 gases of different densities with a small amplitude sinusoidal perturbation to a vertical shock wave. The shock traverses the interface, leaving a sinusoidal vortex sheet on it. The visualization and quantification of this simulation has helped us derive an analytical expression for the circulation deposition. We have determined that in early time the evolution of the interface was similar to that of a vortex sheet governed by the Biot-Savart law. Based on these premises we developed two models for the growth rate of the interface. In one, the vortex sheet retains its sinusoidal character (valid for early time) and in the other, the circulation is lumped into a line vortex at the center (valid for late time).

Analytical results were derived and validated against 2D Euler simulations performed on NCSA's CM5 using our 2nd order Godunov code. The findings were presented at the 20th International Symposium on Shock Waves, Caltech, July 1995

PUBLICATIONS:

The publications which resulted from this grant are listed below (some of these are included with this document):

1993-94

1. On Shock Polar Analysis and Analytical Expressions for Vorticity Deposition in Shock-Accelerated Density-Stratified Interfaces, 1993. R. Samtaney and N.J. Zabusky, Physics of Fluids A 5(6): 1285-1287, June.

2. Sheu, P. and Silver, D. Extending Object-Oriented Databases with Problem Solving and Visualization, Computers & Graphics, Volume 17, Number 4, pp. 447-455, 1993.

3. Circulation Deposition on Shock Accelerated Planar and Curved Density-Stratified Interfaces: Models and Scaling Laws, 1994. R. Samtaney and N.J. Zabusky, Journal of Fluid Mechanics, 269, 45-78.

4. Vorticity Deposition and Evolution of Perturbed 3D Richmyer-Meshkov Environments, 1993. N.J. Zabusky and R. Samtaney, "Proceedings of the 4th International Workshop on the Physics of Compressible Turbulent Mixing," (P.F. Linden, D.L. Youngs & S.B. Dalziel, eds.), 29 March- 1 April, Cambridge,England, Cambridge University Press, 1994, 276-290.

5. Visometrics, Juxtaposition, and Modeling, 1993. N.J. Zabusky, D. Silver, R. Pelz, Vizgroup '93, Physics Today, 24-31, March; and Physical Science Magazine 10, 1993, (and in Japanese).

6. High Performance Computing and Physics, 1993. S.A. Orszag and N.J. Zabusky, Physics Today, 22-23, March.

7. Visualizing Features and Tracking their Evolution, 1994. R. Samtaney, D. Silver, N.J. Zabusky, and J. Cao, IEEE Computer, 27: 20-27, July.

8. Computer Graphics to Visiometrics: Visualization and Quantification of Massive Data Sets, 1994. N.J. Zabusky and D. Silver, McGraw-Hill Yearbook of Science & Technology, 100-103.

9. Silver, D. and N. Zabusky, Vision and Visualization, Proceedings of IEEE Workshop on Visualization and Vision, pp. 55-61, June 1994, Seattle, Washington.

10. Silver, D., R. Samtaney and N. Zabusky, Feature Tracking: Visualizing Amorphous Regions and their Evolutions, Proceedings of SPIE/IS&T Electronic Imaging Science and Technology, Visual Data Exploration and Analysis, Volume 2178, pp. 114-122, February 1994.

11. Near Singular Collapse and Local Intensification of a 'Lissajous-Elliptic' Vortex Ring: Nonmonotonic Behavior and Zero-Approaching Local Energy Densities, 1994. V.M. Fernandez, N.J. Zabusky, and V.M. Gryanik, Phys Fluids. 6(7): 2242-2244.

1995

1. High Gradient Phenomena in Two-Dimensional Vortex Interactions, 1995. H-B. Yao, D.G. Dritschel, N.J. Zabusky, Physics of Fluids 7(3): 539-548.

2. Vortex Intensification and Collapse of the Lissajous-Elliptic Ring: Single and Multi-Filament Bio-Savart Simulations and Visiometrics, 1995. V. Fernandez, N.J. Zabusky, and V. Gryanik, Journal of Fluid Mechanics 299: 289-331.

3. Coherent Structure Visiometrics: From the Soliton to 'HEC', 1995. N.J. Zabusky. presented to KdV '95 Symposium, Amsterdam, Apr.23-26. Published: Acta Applicandae Mathematicae 39. Kluwer Academic Pulishers, Netherlands. 159-172.

4. Nonlinear Sound-Vortex Interaction in an Inviscid Isotropic Fluid: A Two-Fluid Model, 1995. S. Nazarenko, N.J. Zabusky and T. Scheidegger, Phys Fluids A, 7(10): 2407-2419.

5. Visualization and Quantification of Vortex Dominated Flows, 1995. N.J. Zabusky, D. Silver, R. Samtaney, and V. Fernandez, Encyclopedia of Computer Science and Technology, 32(17), 373-387, M. Dekker Publishers.

6. D. Silver, Object Oriented Visualization, IEEE Computer Graphics and Applications, Volume 15, Number 3, pp54-63, May 1995.

7. Collapse, Intensification and Reconnection in Vortex Dominated Flows: Visiometrics and Modeling, 1995. N.J. Zabusky, V.M. Fernandez, D. Silver, Physica D 86:1-11

8. Visualization and Feature Extraction in Isotropic Navier-stokes Turbulence, 1995. V.M. Fernandez, N.J. Zabusky, S. Bhat, D. Silver and S-Y Chen, proceedings of "AVS '95" Conference, Boston, MA, April 19.

9. F. Post, T. Walsum, F. Post and D. Silver, Iconic Techniques for Feature Visualization, in Proceedings of IEEE Visualization 1995, pp 288-295, November 1995, Atlanta, Georgia.

10. M. Dao, D. Silver and T. Cook, Low-Cost Hardware Acceleration of Volume Rendering using FPGA's, IEEE Symposium on FPGAs for Custom Computing Machines, April 1995.

11. Filament Surgery and Temporal Grid Adaptivity Extensions to a Parallel Tree Code for Simulation and Diagnosis in 3D Vortex Dynamics, 1995. V.M. Fernandez, N.J. Zabusky, P. Liu, S. Bhatt and A. Gerasoulis, "Second International Workshop on Vortex Flows and Related Numerical Methods", Montreal, Canada. Aug.19-24.

1996

1. On the Nature of Vortex Interactions and Models in Unforced Nearly-Inviscid Two-Dimensional Turbulence, 1996. D.G. Dritschel, N.J. Zabusky. Physics of Fluids, 8(5): 1252-1256. 96

2. Axisymmetrization of an isolated vortex region by splitting and partial merging of satellite depletion perturbations, 1996 . H-B. Yao, N.J. Zabusky, Physics of Fluids, 8(7): 1842-1847.

3. An Interactive Imaging Environment for Scientific Visualization and Quantification, 1996. A. Feher and N. J. Zabusky, International Journal of Imaging Systems and Technology 7:121-130.

4. Vortex Models for Richtmyer-Meshkov Fast/Slow Environments: Scaling Laws for Interface Growth Rates, 1995. N. Zabusky, J. Ray and R.S. Samtaney. "Proceedings of Physics of Compressible Turbulent Mixing," (eds. R. Young, J. Glimm and B. Boston), 89-97.

5. Vortex Methods for Early and Intermediate Time Richtmyer-Meshkov Environments, 1995. J. Ray, N. Zabusky, and R.S. Samtaney. "Proceedings of 20th International Symposium on Shock Waves (ISSW '95)", (eds. B. Sturtevant, J.E. Shepherd, and H.G. Hornung), World Scientific, 1996, 641-646.

6. Vortex Dominated Flows, 1996. N.J. Zabusky, "Research Trends in Fluid Dynamics", Report from the United States National Committee on Theoretical and Applied Mechanics. (eds.: J.L. Lumley, A. Acrivos, L.G. Leal, S. Leibovich), American Institute of Physics, NY.322- 328.

7. Visiometrics of Complex Physical Processes: Diagnosing Vortex-Dominated Flows, 1996. V.M. Fernandez, D. Silver and N.J. Zabusky, Computers in Physics 10(5): 463-470. Also, cover illustration.

8. Volume Tracking. D. Silver and X. Wang, IEEE Visualization '96 proceedings. October 1996.

9. Visiometrics and modeling in computational fluid dynamics. N.J. Zabusky, D. Silver and V. Fernandez. Mathematics and Computers in Simulation, 40(1996). 181-191.

10. Feature Extraction and Iconic Visualization. T. Walsum, F. Post, D. Silver and F. Post, IEEE Transactions on Visualization and Graphics, July 1996.

11. Visiometrics in Computational Fluid Dynamics, N.J. Zabusky; and Collapse, Intensification and Reconnection in Vortex Dominated Flows: visiometrics and mod eling, N.J. Zabusky, V.M. Fernandez, and D. Silver. "Computational Physics," 199 7.

INVITED PRESENTATIONS

1. "Visiometrics and Modeling", N. Zabusky, Sherwood and NTP meetings in Dallas (1994) and Incline Village,NV (1995).

2. "Feature Tracking," D. Silver, NAS Division, NASA Ames Research Center, November 1993.

3. "Feature Based Algorithms for Visualization and Quantification," D. Silver, Siemens Research Center, Princeton, New Jersey, March 1993.

4. "Visualizing Features and Tracking Their Evolutions," D. Silver, Medical Image Processing Group, University of Pennsylvania, October 1994.

5. "Visualization: Work in Progress," D. Silver, NASA Ames Research Center, June 1994.

6. "Feature Isolation, Tracking and Visualization," D. Silver, Seminar on Scientific Visualization, Dagstuhl, Germany, June 1994.

7. "Concepts, Processes and Methods for Two Dimensional Vortex Dynamics: Algorithms for visiometrics (coherent vortex structure extraction and tracking), axisymmetrization, gradient intensification and merger.", N. Zabusky Australian Summer School in Computational Physics: 5-25 Jan 1996.,Canberra, Australia . Contact Prof H. Gardner, Convenor NIFS: 26 Jan - 30 April 1996, Nagoya Japan. Contact Prof T. Sato. (Head of Department of Simulation and Modeling).

8. "Flows: Visiometrics, Juxtaposition & Modeling Visiometrics. (Coherent Structure Extraction and Tracking in Massive 3D Data Sets; Juxtaposition : Pseudo-spectral (Incompressible & Compressible) & Biot-Savart (Incompressible, single & multifilament) Field and Lab experiments on videos.)", N. Zabusky, Dept of Applied Physics : Nagoya Univ. 18 April 1996.Contact Prof Y. Kaneda (Head of Department)

9. "Shock Interface-and-Bubble Interactions: Visiometrics and Reduced Vortex Models for the Richtmyer-Meshkov Environment at Early and Intermediate Epochs. ", N. Zabusky, ILE : 28 march 1996, Osaka Japan. Contact Prof K. Mima (Director) Japanese Physical Society, Annual Meeting: 3 April '96 Kanazawa, Japan. Contact Prof T. Kambe, Prof . Univ of Tokyo Inst. of Fluid Science: xx April 1996, Sendai , Japan. Contact Prof K. Takayama (Head)

10. We are participating in the MIX 95 meeting on compressible fluid dynamics and mixing at Stony Brook, NY in July 1995 and the ISSW shock wave meeting at Caltech in August of 1995. Tentative title : " Vortex models and growth rates for early and intermediate time Richtmyer - Meshkov environments " .

11. R Samtaney and N. Zabusky have been invited to give a talk at the SIAM meeting on the RM work in Charlotte, NC in Oct 1995. Title: " Reduced Vortex Models for the Richtmyer-Meshkov (Shock-accelerated interface) environment beyond early time. "

12. "Feature Extraction and Tracking", D. Silver, Institute for Computer Applications in Science and Engineering, NASA Langley Research Center, Hampton, VA, August 1996.

References

[1] S. Bhat. Segmentation of Unstructured Datasets, 1996. MS. Thesis, Dept. of Electrical and Computer Engineering, Rutgers Universi ty.

[2] F. Bitz and N.J. Zabusky. DAVID and Visiometrics: Visualizing, Diagnosing and Quantifying Evolving Amorphous Objects. *Computers in Physics*, pages 603–614, November/December 1990. Also, cover of this issue showing winding reconnection.

[3] S. Parker J. Cummings and R. Samtaney. Visualization of plasma turbulence. *IEEE Computer Graphics and Application*, pages 7–10, March 1995.

[4] D. Silver and X. Wang. Volume Tracking. In *Proceedings of IEEE Visualization '96*, pages 157–164, San Francisco, Ca, October 1996.

[5] R. Samtaney, D. Silver, N. Zabusky, and J. Cao. Visualizing Features and Tracking Their Evolution. *IEEE Computer*, 27(7):20–27, July 1994.

[6] Ravi Samtaney, Deborah Silver, Norman Zabusky, and Jim Cao. Visualizing features and tracking their evolution. *IEEE Computer*, 27(7):20–27, July 1994.

[7] X. Wang and D. Silver. Octree-based Algorithm for 3D Feature Tracking. Technical Report TR 204, CAIP center, Rutgers University, Piscataway, NJ, 1995.

[8] X. Wang and D. Silver. Volume Tracking – Video Animation, 1995. MPEG version on http://www.caip.rutgers.edu/vizlab.html.