CS 523 Scientific Visualization
Spring Quarter 1998

Instructor: Chris Johnson, Ph.D.

Time: T,Th 2:15 - 3:30 p.m.

Place: EMCB 112

Office: 3440 MEB

Phone: 581-7705

Email: crj@cs.utah.edu

Class web page: http://www.cs.utah.edu/∼cs523

T.A.: TBA

Text: The Visualization Toolkit, W. Schroeder, K. Martin, and W. Lorensen, 2nd Edition, Prentice Hall, 1998.

Course Philosophy: As Scientific Visualization is important to many (most) areas of science and engineering, students in this course have a variety of backgrounds, expertise, and needs. As such, we will try and cover topics common to many areas of visualization while at the same time allowing individuals to learn specific techniques and/or applications via a visualization project. Scientific visualization can be approached from a very abstract and/or from a very practical perspective. In this course, we'll focus on applications, while at the same time learning some of the underlying theory.

Course Goals: Upon completion of this course, the student should

- know the important definitions and current issues in scientific visualization,
- know commonly used algorithms and techniques in scientific visualization,
- have seen and discussed examples of visualization in a variety of fields,
- be able to critique the effectiveness of a scientific visualization,
- be able to use at least one scientific visualization software package,
- know where to locate further visualization resources,
- have completed a project in scientific visualization.

Assignments: There are two main types of assingments for this course. One is in the form of in between class homework that will primarily consist of using one of the scientific visualization programs. The second will be in the form of a scientific visualization project. This project can be visualization of data you have collected from a simulation and/or experiment, development of a new software tool(s) for visualization, or a theoretical investigation of a topic in visualization. My goal is to supply the student with as close to *real life* applications as possible within the confines of a quarter long class.

Languages: We expect students to be able to program in some high-level language (C, C++, Fortran, etc.).

Grades: Final course grades will be computed according to 70% Homework and Labs and 30% Final Project.

Incompletes: As the project is due by the end of the quarter, in past quarters it has turned out that some people do not wisely schedule their time and do not finish their projects. They then want to take an incomplete and finish the project sometime in the summer. I only give incompletes very rarely and only for truely unusual circumstances (death in the family, etc.), so please work to finish your final project on time.

Software Tools: We anticipate having the following software packages available for use:

- Visualization Toolkit (VTK)
- Maple
- MatLab
- IBM Data Explorer
- Wavefront
- SCIAN
- SGI Iris Explorer
- SoftImage

Visualization facilities: We will be using the Computational Engineering and Science (CES) lab, 3161 MEB. The CES lab has nine SGI Indigo2s with Extreme level graphics. The lab has 24 hour ID card access.

Syllabus for CS 523

Week 1. Overview of scientific visualization and *gee whiz* demonstrations.

Week 2. Simple graphical techniques and programs.

Week 3. Data structures in scientific visualization.

Week 4. Computational geometry - surface and volume representations.

Week 5. Visualization software; Geometric modeling systems.

Week 6. Surface visualization techniques.

Week 7. Volume visualization techniques.

Week 8. Vector field visualization.

Week 9. Animation and video.

Week 10. Color, hue, lighting; Presentation of final projects.

Note: During the quarter, we will have two to three guest lectures on selected topics.

Scientific Visualization Project

Due dates: Project description **due May 5**. Project report due on **May 19**. The final project is **due June 9**.

The scientific visualization project can be (1) visualization of simulation and/or experimental data you have, (2) development of new software tools for visualization and/or creation of a new module(s) for an exisiting visualization package, or (3) conducting a theoretical investigation of some aspect of scientific visualization and writing a paper discussing your results.

It is your responsibility to pitch your project at the appropriate level. Challenge, but do not exhaust, yourself. Please ensure that even if you underestimate the difficulty of your project, you will have something to hand in by the due date (choosing too difficult a project is not a valid reason for an incomplete).

Group projects are allowed, however, the size and difficulty of the project should reflect the number of people involved in a single project.

On May 5 your project design report is due. This should be a well thought out, well-written 1-3 page description of your proposed project. It should outline any necessary background, specifically what goals you plan on accomplishing, and what you will need to do in order to accomplish your goals. You will also need to include what software/hardware you plan to use, and what you intend to hand in (i.e. what are the "deliverables"). On May 19 your progress report is due. This report should contain a description of how much of your project is completed at this point and what still remains to be done. This is the time to make modifications (which you must justify) and present a timeline for completion of the project.

In grading the projects, we will be looking for a well-designed, substantial, interesting project. Furthermore, your implementation, content and style of the final results should be of high quality. A final criteria for grading is that the progress report and final report are handed in on time.

You will demonstrate your final projects on Tuesday, June 9. A final project sign-up sheet will be handed out in class for you to schedule a time. Demonstrations will typically take 15-20 minutes.

Project Design Report

Please hand in your Project Design Report by **May 5** (or sooner). It should contain the following information.

Student Name(s):

Project title:

- Give an overview of the project.
- Why is this project important and/or interesting?
- If you are doing a programming project, list the hardware and software you will be using:
- What have you done thus far and what will you have to do to complete this project?
- When the project is completed, how *specifically* can we evaluate how successful it is?
- Any other useful information:

Project Progress Report

Please hand in your Project Progress Report by **May 19** or sooner. It should contain the following information.

Student Name(s):

Project title:

- How much have you completed and what still needs to be done on the project?
- Have you had to make any changes in your project description? If so, please list and justify the changes.
- Any additional information:

Project Final Report

You will be required to hand in your Project Final Report on **June 9**. Your final report should contain the following information.

Student Name(s):

Project title:

- Provide a brief description of your project and how to run it if it is not self-explanatory.
- Outline what you learned from doing this project.
- If you have not accomplished all the goals of your project, or if you have exceeded them, describe how the finished project differs form the description in your progress report.
- Evaluate your project: how successful do you think it was? What are the strengths and weaknesses of your project?
- Any other comments useful for me in evaluating your project:

References for CS 523

The following list contains some references you may want to read for this class. The list here is selective rather than exhaustive. If you find any other good references I should put on the list, please let me know.

General References

1. *The Visualization Toolkit: An Object Oriented Approach to 3D Graphics*, W. Schroeder, K. Martin, and B. Lorensen, Prentice Hall Press, 2nd Edition, 1998. (This is an excellent book on graphics and visualization and even includes a CD ROM of programs. For people really interested in graphics and visualization, this book is highly recommended. The only drawback for some scientists and engineers is that the book uses C++).

2. *Scientific Visualization*, L. Rosenblum, R.A. Earnshaw, J. Encarnacao, H. Hagen, A. Kaufman, S. Klimenko, G. Nielson, F. Post, D. Thalmann, eds., IEEE Computer Society Press and Academic Press, 1994. (This book is an edited collection of techniques in scientific visualization by many of the top people in the field. Drawbacks include an uneven level/presentation of the material and the cost of the book).

3. *Focus on Scientific Visualization*, H.Hagen, H.Müller, and G. Nielson, (eds.), Springer-Verlag, 1993. (This is about as close to a decent textbook as there is for scientific visualization. It contains chapters by several of the top people in the field. The major drawbacks are that the treatment is spoty and the cost of the book is high - approx. $80.00).

4. *Visual Cues: Practical Data Visualization*, P.R. Keller and M.M. Keller, IEEE Computer Society Press, 1992. (This books contains a few chapters on data visualization guidelines, and numerous visualization examples, each with a short explanation.)

5. *Visualization of Natural Phenomena*, R.S. Wolff and L. Yaeger, Springer-Verlag, 1992. (Contains a readable overview of many aspects of visualization. Book also includes a Macintosh CD-ROM.)

6. *Volume Visualization*, A. Kaufman (ed.), IEEE Computer Society Press, 1990. (An extensive compilation of research articles on volume visualization.)

7. *Visualization in Scientific Computing*, G.M. Nielson and B. Shriver (eds.), IEEE Computer Society Press, 1990. (Another collection of research articles on visualization. Covers a wide variety of topics.)

8. *The Second Computer Revolution: Visualization*, R.M. Friedhoff and W. Benzon, Harry N. Abrams, Inc., (1989). (This is a coffee table type book, but it does have a good overview of a few areas as well as a wealth of pictures.)

9. *Computer Visualization, Graphics Techniques for Engineering and Scientific Analysis*, Richard S. Gallagher (ed.), CRC Press, 1994.

10. Other books include: *Scientific Visualization — Techniques and Applications*, K.W. Brodlie, L.A. Carpenter, R.A. Earnshaw, J.R. Gallop, R.J. Hubbold, A.M. Mumford, C.D. Osland, P. Quarendon, Springer-Verlag, 1992; *Visualization in Scientific Computing*, M. Grave, Y. Le Lous, and W.T. Hewitt, (eds.), Springer-Verlag, 1994; *Visualization Today*, H.-G. Pagendarm, Springer-Verlag, 1994; *Perceptual Issues in Visualization*, G. Grinstein, and H. Levkowitz, Springer-Verlag, 1994; *State of the Art in Computer Graphics*, D.F. Rogers and R.A. Earnshaw, Springer-Verlag, 1994; *Graphics Modeling and Visualization in Science and Technology*, M. Göbel and J.C. Teixeira, (eds.), Springer-Verlag, 1993; *Advances in Scientific Visualization*, F.H. Post, and A.J.S. Hin, (eds.), Springer-Verlag, 1993; *An Introductory Guide to Scientific Visualization*, R.A.Earnshaw, and N.Wiseman, Springer-Verlag, 1992; *CG International '91 — Scientific Visualization of Natural Phenomena*, N.M. Patrikalakis, (ed.), Springer-Verlag, 1991; *Visualization in Supercomputing*, R.H.Mendez, (ed.), Springer-Verlag, 1991.

11. Proceedings of the *IEEE* visualization conferences. For example, Proceedings of Visualization '92, A. Kaufman and G. Nielson, (eds.), IEEE Computer Science Press, 1992. (The *IEEE* conference proceedings are an excellent reference for current work in visualization. The topics covered in the proceedings range from algorithms to applications to hardware — in short, most important topics are healthily represented.)

12. IEEE Transactions on Visualization and Computer Graphics.

Introduction

1. "Visualization: Expanding Scientific and Engineering Research Opportunities," T.A. DeFanti, M.D. Brown, and B.H. McCormick, *Computer*, August 1989, 12–25; also in *Visualization in Scientific Computing*, G.M. Nielson and B. Shriver (eds.), IEEE Computer Society Press, 1990, 32–47.

2. "Visualization in Scientific Computing," B.H. McCormick, T.A. DeFanti, and M.D. Brown, *Computer Graphics* **21**(6), 1987. (A report which played an influential role in the growth of visualization.)

Computer Graphics

1. *Computer Graphics: Principles and Practice* (2nd Ed.), J.D. Foley, A. van Dam, S.K. Feiner, J.F. Hughes, Addison-Wesley, 1990. (This is the main graphics reference book.)
2. The *Graphics Gems* sequence of books. For example, *Graphics Gems II*, James Arvo (ed.), Academic Press 1991. (This sequence of books contains numerous small graphics notes and programming tips.)
3. *Advanced Animation and Rendering Techniques*, Alan Watt and Mark Watt, Addison-Wesley, 1992. (A good book on advanced graphics.)
4. *ACM Transactions On Graphics* (journal)
5. *Computer Graphics* (journal) (See in particular the yearly SIGGRAPH proceedings.)
6. *IEEE Computer Graphics & Applications* (journal)

Software

1. *IRIS Explorer User's Guide*, Silicon Graphics Computer Systems, Mountain View, CA, 1991.

Data Presentation

1. "Visualizations Idioms: A Conceptual Model for Scientific Visualization Systems," R.B. Haber and D.A. McNabb, in *Visualization in Scientific Computing*, G.M. Nielson and B. Shriver (eds.), IEEE Computer Society Press, 1990, 74–93. (One theme of this article is that there are numerous waysto display data, and the more one ways one has access to, the more useful the visualization process is.)
2. *The Graphical Display of Qualitative Information*, E. Tufte, Graphics Press, 1983. (An excellent and sharply written book on classical data presentation.)
3. *Graphics and Graphic Information Processing*, J. Bertin, trans. by W. Berg and P. Scott, Walter de Gruyter, Berlin, 1981. (Another classic reference on data presentation.)
4. *The Elements of Graphing Data*, W.S. Cleveland, Wadsworth, Monterey, CA. 1985.
5. *Pictorial communication in virtual and real environments*, Stephen R. Ellis (ed.), Taylor and Francis, London, 1991.

6. "Fourteen ways to say nothing with scientific visualization," A. Globus and E. Raible, *Computer*, **27**(7), (1994), 86–88.

Multivariate Visualization

1. "A survey and characteristics of multidimensional presentation techniques," E. Cluff, R.P Burton and W.A. Barrett, *Journal of Imaging Technology*, **17**(4), (1991), 142–153.

2. "Representation and Display of Vector Field Topology in Fluid Flow Data Sets," J. Helman and L. Hesselink, *Computer*, August 1989, 27–36; also in *Visualization in Scientific Computing*, G.M. Nielson and B. Shriver (eds.), IEEE Computer Society Press, 1990, 61–73.

3. "Visualization of 2nd order tensor fields and matrix data," T. Delmarcelle and L Hesselink, in *Visualization '92*, IEEE Computer Society, (1992), 316–323.

4. "Interactive analysis of the topology of 4D vector fields," R. Dickinson, *IBM Journal of Research and Development*, **35**(1), (1991), 59–66.

5. "Parallel coordinates: a tool for visualizing multi-dimensional geometry," A. Inselberg, in: *Proceedings of IEEE '90 Visualization*, (1990), 361–378.

6. "Visualizing vector field topology in fluid flows," J.L. Helman and L. Hesselink, *IEEE Computer Graphics and Applications*, **11**(3), (1991), 36–46. (This paper won the IEEE Computer Graphics and Applications best article award for 1991.)

7. "Direct Volume Visualization of Three-Dimentional Vector Fields," R. Crawfis and N. Max, *ACM Workshop on Volume Visualization*, 1992, 55–60.

User Interface Issues

1. "Interactive Manipulation and Display of Two-Dimensional Surfaces in Four-Dimensional Space," D. Banks, *1992 Symposium on Interactive Graphics* (special issue of *Computer Graphics*), 1992, 197–207.

2. "Snap-Dragging in Three Dimensions," E. Bier, *Computer Graphics*, **24**(2), 1990 (special issue on 1990 Symposium on Interactive 3D Graphics), 193–204.

3. "Visualization Methods and Simulation Steering for a 3D Turbulence Model of Lake Erie," R. Marshall, J. Kempf, S. Dyer, C.-C. Yen, *Computer Graphics*, **24**(2), 1990 (special issue on 1990 Symposium on Interactive 3D Graphics), 89–98.

4. “Project GROPE — Haptic Displays for Scientific Visualization,” F.P. Brooks, M. Ouh-Young, J.J. Batter, P.J. Kilpatrick, *Computer Graphics*, **24**(4), 1990 (SIGGRAPH ’90 Proceedings), 177–185.

5. “Interactive Graphics for Plastic Surgery: A Task-level Analysis and Implementation,” S. Pieper, J. Rosen, and D. Zeltzer, *Computer Graphics* (special issue on the 1992 Symposium on Interactive 3D Graphics).

6. “Surround-Screen Projection-Based Virtual Reality: The Design and Implementation of the CAVE,” C. Cruz-Neira, D.J. Sandin, and T.A. DeFanti, *Computer Graphics*, 1993 (SIGGRAPH ’93 Proceedings), 135–142.

7. “Virtual Reality on Five Dollars a Day,” R. Pausch, *Proceedings of ACM CHI’91 Conference on Human Factors in Computing Systems*, 1991, 265–270. (Describes how to construct and use a low-cost VR set-up).

Techniques and Algorithms

1. “Marching Cubes: A High Resolution 3D Surface Construction Algorithm,” W.E. Lorensen and H.E. Cline, *Computer Graphics*, **21**(4), 1987, 163–169 (see also “Additional References to ‘Marching Cubes’ ” (to correct an error in the original algorithm), *Computer Graphics* **22**(2), 1988, 72–73).

2. “An Efficient 3D Visualization Technique for Finite Element Models and other Coarse Volumes,” R.S. Gallagher and J.C. Nagtegaal, *Computer Graphics* **23**(3), (1989), 185–194.

3. “Octrees for Faster Isosurface Generation,” J. Wilhelms and A. Van Gelder, ACM Transactions on Graphics, **11**(3), (1992), 201–227. (This paper contains the octree variant of marching cubes which we will overview in class.)

4. “Decimation of Triangle Meshes,” W.J. Schroeder, J.A. Zarge and W.E. Lorensen, *Computer Graphics*, **26**(2), 1992, 65–70.

5. “Retiling Polygonal Surfaces,” G. Turk, *Computer Graphics* **26**(2), 1992, 55–64.

6. “Surfaces from Contours,” D. Meyers, S.Skinner, and K. Sloan, ACM Transactions on Graphics, **11**(3), (1992), 228–258. (A discussion of, and algorithm for, joining slices of contour data to develop surfaces.)

Volume Visualization

1. "A Survey of Algorithms for Volume Visualization," T.T. Elvins, *Computer Graphics* **26**(3), 1992, 194–201. (A good, brief, overview of the many volume visualization techniques.)

2. *Volume Visualization*, A. Kaufman (ed.), IEEE Computer Society Press, 1990.

3. "Footprint Evaluation for Volume Rendering," L. Westover, *Computer Graphics* **24**(4), 1990, 367–376. (Splatting.)

4. "Volume Rendering," Drebin, Carpenter, and Hanrahan, *Computer Graphics* **22**(4), 1988, 65–74. (A very influential paper from PIXAR. One of the seminal volume visualization papers.)

5. "A Rendering Algorithm for Visualizing 3D Scalar Fields," P. Sabella, *Computer Graphics* **22**(4), 1988, 51–58.

6. "V-BUFFER: Visible Volume Rendering," Upson and Keeler, *Computer Graphics* **22**(4), 1988, 59–64.

Data Interpolation and Approximation

1. *Curves and Surfaces for Computer Aided Geometric Design*, G. Farin, 2nd ed., Academic Press, 1990. (A good general reference for curve and surface use in design.)

2. "Triangulations in CAGD," L.L. Schumaker, *IEEE Computer Graphics & Applications* **13**(1), 1993.

3. "Scattered Data Modeling," G.M. Nielson, *IEEE Computer Graphics & Applications* **13**(1), 1993.

4. "Scattered data interpolation in three or more variables," P. Alfeld, in "Mathematical Methods in Computer Aided Geometric Design," T. Lyche and L.L. Schumaker (eds.), Academic Press, (1989), 1–33. (This paper, while rather terse (even at its length of 33 pages) nicely overviews the many different approaches to higher dimensional scattered data interpolation. It also contains a lengthy bibliography.)

5. "Visualization and modeling of multivariate scattered data," G. Nielson, T. Foley, B. Hamann and D. Lane, IEEE Computer Graphics and Applications, **11**(3), (1991), 47–55. (Contains information on modeling and displaying surfaces and volumes obtained from scattered data.)

6. "Visualizing function on a sphere," H. Pottmann, H. Hagen and A. Divivier, *The Journal of Visualization and Computer Animation*, **2**, (1991), 52–58.

Special Issues and Conference Proceedings

1. *Computer*(special issue on visualization), **26**(7), 1994.
2. *IEEE Computer Graphics and Applications* (special issue on graphics in medicine), **13**(6), 1993.
3. *IEEE Computer Graphics and Applications* (special issue on visualization), **12**(4), 1992.
4. *1992 Symposium on Interactive Graphics* (special issue of *Computer Graphics*), 1992.
5. *IEEE Computer Graphics and Applications* (special issue on scientific visualization), **11**(3), 1991.
6. *Computer Graphics* (special issue on the San Diego Conference on Volume Visualization), **24**(5), Nov. 1990.
7. *IEEE Transactions on Biomedical Engineering* (special issue on interaction with and visualization of biomedical data), **37**(8), August (1990).
8. *IEEE Computer Graphics and Applications* (special issue on medical imaging), **10**(2), March 1990.
9. *Computer Graphics* (special issue on 1990 Symposium on Interactive 3D Graphics), **24**(2), March 1990.
10. *The Visual Computer*, **6**(1), Feb. 1990.
11. *Computer*, **22**(8), August 1989.
12. *Computer and Graphics*, **13**(2), April 1989.
13. *Proceedings of the Chapel Hill Workshop on Volume Visualization*, University of North Carolina Press, 1989.
14. *Computers in Physics*, special issue on scientific visualization, **2**(3), 1988.
15. *IEEE Computer Graphics and Applications* (special issue on medical imaging), **5**(12), December 1985.
16. *IEEE Computer Graphics and Applications*, special issue on medical imaging, **3**(5), August 1983.

Other resources

1. ACM Siggraph and IEEE have a few videotapes for sale involving visualization. These are usually expensive, and take a few weeks to order and receive. See me if you'd like a list of the videos.

2. There is a newsgroup comp.graphics.visualization that, like most newsgroups, contains a wealth of useless information, and an occasional interesting posting. In particular, the FAQ (frequently asked question) posting contains a wealth of information, some of which may be of interest. A number of other newsgroups will cover particular aspects or applications of visualization.

3. *Annotated Bibliogragraphy*, Keith Voegele, in *Visualization in Scientific Computing*, G.M. Nielson and B. Shriver (eds.), IEEE Computer Society Press, 1990, 5–25.

4. *Annotated Bibliogragraphy*, R. Yagel and A. Kaufmann, in *Volume Visualization*, A. Kaufman (ed.), IEEE Computer Society Press, 1990, 439–464.

Miscellaneous

1. "Research issues in scientific visualization," L. Rosenblum et al., *IEEE Computer Graphics and Applications*, **14**(2), (1994) 61–85.

2. "Color and Sound in Algorithm Animation," M. H. Brown and J. Hershberger, *Computer* **25**(12), 1992, 52–63.

3. "Navigating the Video Maze," R. Myerson and T. Rhyne, *Computer Graphics* **26**(3), 1992, 190–193.

4. "Pictures, Poseurs, and Posers," S.J. Rueff, *Computer Graphics* **26**(3), 1992, 202–204.

5. "Take a Broader View of Scientific Visualization," R.A. Becker and W.S. Cleveland, *Pixel*, **2**(2), 1991, 42–44.

6. *3-D Imaging in Medicine*, J.K. Udupa and G.T. Herman (eds.), IEEE Computer Society Press, 1990.

7. *3-D Imaging in Medicine: Algorithms, Systems, Applications*, K.H. Hoene, H. Fuchs and S.M. Pizer (eds.), Springer-Verlag, 1990.

8. *Digital Picture Processing*, vols. 1&2, A. Rosenfeld and A. Kak, Academic Press, 1976.

9. "Visualization of Injection Molding," R. Ellson and D. Cox *Simulation*, **51**(5),1988, 84–188.

10. "A Language for Molecular Visualization," T. Palmer, *IEEE Computer Braphics and Applications*, **12**(3), 1992, 23–32.

11. "Linkwinds: Interactive Scientific and Data Analysis and Visualization," A.S. Jacobson, A.L. Berkin and M.N. Orton, *ACM Transactions on Graphics* **37**(4), 1994, 43–52.

12. "SIGGRAPH '92 Showcase," special section in *Communications of the ACM*, **35**(6), (1992), 42–84. (This special section consists of an introduction and 4 articles. The Showcase was a research exhibit shown at SIGGRAPH '92, and focused on visualization in a networked environment. The four articles — "Metacomputing," "The distributed laboratory: an interactive visualization environment for electron microscopy and 3D imaging," "The CAVE: audio visual experience automatic virtual environment," and "Modeling and analysis of empirical data in collaborative environments" discuss areas like interactivity, virtual reality, supercomputing, networks, and collaboration as they relate to current research.)

13. "Mosaic and the World-Wide Web," R.J. Vetter, C. Spell and C. Ward, *Computer* **27**(10), (1994), 49–58. (This is a good introduction to these topics.)

14. *IEEE Computational Science and Engineering* (journal).