Title: SCIRun: Applying Interactive Computer Graphics to Scientific Problems

Authors: Steven G. Parker and Christopher R. Johnson

Address: Department of Computer Science
University of Utah
Salt Lake City, UT 84112

Office Phone: (801) 581-7705 (crj)
Home Phone: (801) 487-5440 (crj)
Fax: (801) 581-5843

Email: (sparker,crj)@cs.utah.edu
Web: http://www.cs.utah.edu/~sci/

Background: Christopher Johnson received his Ph.D. from the University of Utah in 1989. He is an Associate Professor in the Department of Computer Science at the University of Utah. His research interests are in the area of scientific computing and scientific visualization. Professor Johnson was awarded a FIRST Award from the NIH in 1992, a National Young Investigator (NYI) Award from the NSF in 1994, and the Presidential Faculty Fellow (PFF) Award in 1995. He heads the Scientific Computing and Imaging (SCI) research group at the University of Utah.

Steve Parker is a Ph.D. candidate in the Department of Computer Science at the University of Utah. His research interests include computational steering, scientific computing, visualization, parallel programming, and graphics. In 1994 he was awarded a Computational Science Graduate Fellowship by the Department of Energy.

Brief description: We show how digital technologies are used in SCIRun, a computational programming and steering environment. We explore these technologies as applied to problems in computational medicine and computational fluid dynamics. Several digital technologies are explored including graphical user interfaces, high performance graphics hardware, 3D interaction, and scientific visualization.

Type of presentation: Interactive demonstration.

Estimate of time required to demonstrate the application: 40-50 minutes.

Introduction

In this demonstration, we show how several different digital technologies are used within SCIRun, a computational programming and steering environment. We explore how graphical user interfaces, high performance graphics hardware, 3D interaction, scientific visualization and advanced rendering methods are applied to problems in computational medicine and computational fluid dynamics. We demonstrate how the foundations of at least 14 SIGGRAPH papers from the past 13 years have contributed to the individual applications and how these applications have been integrated into a single interactive, visualization-based application for solving problems in computational science and engineering.

The SCIRun environment

SCIRun is a framework in which large-scale computer simulations can be composed, executed, controlled and tuned interactively. Composing the simulation is accomplished through a visual programming interface to a dataflow network. To perform the simulation, one specifies parameters with a graphical user interface [1], [2] rather than with the traditional text based datafile. Steering a simulation involves making changes to simulation parameters as the program executes (i.e. changing model geometry, tweaking intermediate data values, modifying solution algorithms).

The SCIRun system implements an improved model for scientific computing. This model relies on modern computing technologies, such as graphical user interfaces and 3D graphics, to provide a simpler but equally expressive format to investigate complex scientific problems. The increased flexibility attempts to provide a "computational workbench" for scientific computing. Within this workbench new experiments are formed, new methods are explored, and tedious coding is kept to a minimum (through code modularity and reuse, interchangable pieces, and standardization).

SCIRun utilizes a visual programming environment [3], [4], [5], [6] to interactively compose new simulations and to facilitate the specification of input data and computational parameters. In addition to traditional mouse-based user interfaces, SCIRun relies heavily on "3D Widgets" [7], [8], [9], [10] for complex 3D user interaction. Traditional 2D user interfaces have proven inadequate for specifying positions, shapes and/or other parameters in three-dimensional spaces. A 3D widget consists of extra objects that are placed in views of the visualization, and mouse interaction with these objects can provide complete control over many 3D parameters. For example, streamline algorithms often use a "rake," composed of cylinders and spheres, to interactively specify an array of starting points for particle advection. Integration of 3D widget objects with other objects in the scene assist the user to understand the location of the 3D widget within the dataset. The widgets can be interactively moved with a 2D mouse, and when coupled with view rotations, the user can move them to any point in 3D space.

At each stage of the computation, advanced visualization methods such as isosurface extraction [11], volume rendering [12], streamline advection and line integral convolution [13], [14] are used to present the data to the scientist. These representations are rendered using high speed rendering hardware [15], [16], [17], to allow interactive exploration [18] of the data. The scientist can then use the 2D and 3D user interfaces to control the various parameters. As soon as new solutions are available, this data is presented to the scientist. In this manner, the scientist is able to make rapid changes and see how those changes affect the numerical models. Once important solutions have been obtained, the same visualizations may be used to present results of the science under study [19].

Applications

SCIRun was designed as a tool to investigate a class of scientific problems called 'field problems." This class encompasses the majority of the problems solved in computational science and engineering applications. During the demonstration, we will showcase a few of these applications, including the electrical simulation of an implantable defibrillation device and an interactive fluid dynamics problem.

Application: Simulation of implantable defibrillation devices

Every year, 500,000 people die suddenly because of abnormalities in their hearts' electrical system (cardiac arrhythmias) and/or from coronary heart disease. While *external* defibrillation units have been in use for some time, their use is limited because it takes such a short time for a heart attack victim to die from insufficient oxygen to the brain. Lately, research has been initiated to find a practical way of implanting electrodes within the body to defibrillate a person's heart automatically upon onset of cardiac fibrillation. Because of the complex internal structure of the human thorax, and the lack of sophisticated thorax models, much past design work on defibrillation devices has relied on animal studies. Due to the drastic differences between animal geometries and human geometries, these experiments do not accurately predict the effects of the shock on a human heart. In order to perform these studies (and keep the animals alive), we have constructed a large-scale computer model of the human thorax, the Utah Torso Model [20], for simulating both the endogenous fields of the heart and applied current sources (defibrillation devices). We are also able to simulate the multitude of electrode configurations, electrode sizes, and magnitudes of defibrillation shocks, via computer modeling. Given the large number of possible external and internal electrode sites, magnitudes, and configurations, it is a daunting problem to computationally test and verify various configurations. For each new configuration test, geometries, mesh discretization levels, and a number of other parameters must be changed.

To meet this challenge, we are using SCIRun to design internal defibrillator devices and measure their effectiveness in an interactive graphical environment. Using SCIRun, engineers are able to design internal defibrillation devices, place them directly into the computer model, and automatically change parameters (size, shape and number of electrodes) and source terms (position and magnitude of voltage sources). Furthermore, engineers can use the interactive visualization capabilities to visually gauge the effectiveness of their design in terms of distribution of electrical current flow and current densitities through critical internal organs.

These computational models can create data that is impossible or impractical to measure. Computer graphics plays a key role in visualizing this data, and provides the medical researcher with a powerful tool for interacting with the problem.

Application: Computational Fluid Dynamics

In contrast to the bioelectrical problem described above, CFD visualizations often have a strong physical analog (streamlines, surface ribbons, smoke pots, etc.). Furthermore, the application of computer graphics has also been able to expose new perspectives on the problem that has not been possible to generate by conventional means, i.e. isosurfaces in a windtunnel. In this application we will show the application of these technologies to familiar problems in computational fluid dynamics. Instead of the off-line simulation mode, where large datafiles are stored to disk, we will demonstrate how computer graphics can illuminate the progression of the numerical simulations. Computational parameters can be changed interactively such that the researcher can obtain direct visual feedback from changing parameters.

Challenges Experienced

When trying to mix computing and visualization, we find that the visualization often takes time away from the computing. If this penalty is too large, scientists will not be inclined to use technology. To minimize the impact on computation, we offload visualization tasks to other processors where possible, and use relatively simple graphics for interactive exploration and steering.

The number of elements required to accurately compute a model is usually significantly higher than the number of elements required to display an accurate picture of that model. As an example, an isosurface of a cranial bioelectric simulation generated several million triangles for display. This isosurface could be accurately displayed using a few thousand larger triangles, but algorithms for decimating unstructured surfaces are not yet fast enough to be interactive.

Another significant challenge is that many hardware and software rendering environments are suited for static or mostly static scenes. For scientific visualizations where a large amount of data is changing at each time step, it does not make sense to maintain a large display list of triangles.

Perhaps the greatest challenge of all is the age old problem of figuring out how to present data to the scientist with a minimal amount of confusion. This subject was the focus at a SIGGRAPH '93 session "How to Lie and Confuse with Visualization," and has been the subject of many a similar panel at the *IEEE Visualization Conference* each year.

Plan for conveying SCIRun in a theater-style setting

For the presentation of SCIRun, we are making plans with SGI to provide a computer that can demonstrate these applications interactively. The presentation will proceed with overviews of the following components of the SCIRun computational steering system:

- The SCIRun user interface and visual programming environment
- Computational modules
- Interactive steering of a CFD simulation
- Visualization modules
- Intrepreting the visual output - the story behind the picture
- Interactive steering of a cardiac defibrillator simulation
- 3D user interaction and 3D widgets in scientific visualization

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