Scientific Visualization

Spring 2018

Center for Data Science

New York University

Claudio Silva Gustavo Nonato

Lecture 1: Introduction

Couser Overview

Couser Overview

Date	Content
23/01	Introduction to Scientific Visualization: Background, Scientific Visualization, Visualization pipeline. (Gustavo)
30/01	Modeling data for visualization: Data types, Interpolation, Meshes and grids, Data structures (Gustavo)
06/02	Basic Plotting: 1D and 2D (Claudio)
13/02	Color and Human Perception (Claudio's invited speaker)
20/02	Basics of Computer Graphics: OpenGL, Shaders and WebGL (Alex)
27/02	Indirect Volume Rendering - Part I: Isosurface extraction (Gustavo)
06/03	Direct Volume Rendering – Part I: Foundations, Transfer functions, Lighting models (Alex)
13/03	**Spring Recess - No Class**
20/03	**Mid-term Exam**
27/03	Indirect Volume Rendering – Part II: Quality & Computational Aspects (Gustavo)
03/04	Direct Volume Rendering - Part II: Speed up, Handling large data (Alex)
10/04	Visualizing Vector and Tensor Fields (Claudio)
17/04	Topological Methods - Part I (Harish)
24/04	Topological Methods - Part II (Harish)
01/05	**Final project presentations**

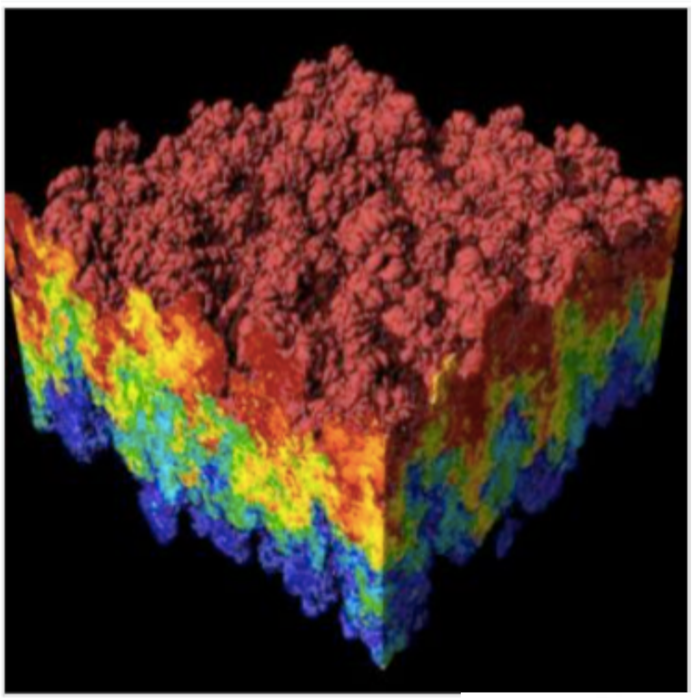
Couser Overview

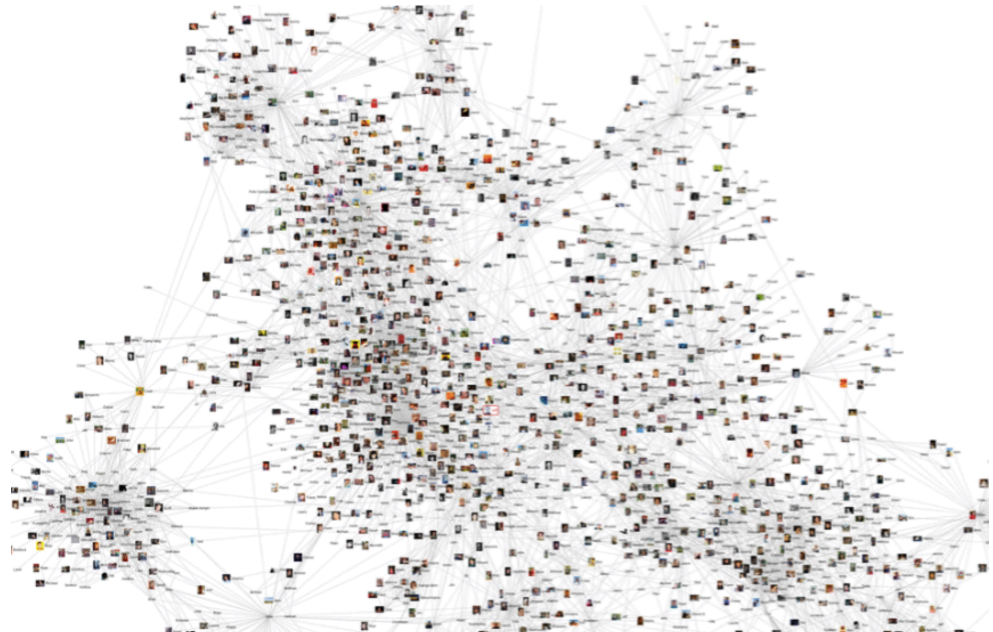
Evaluation Plan

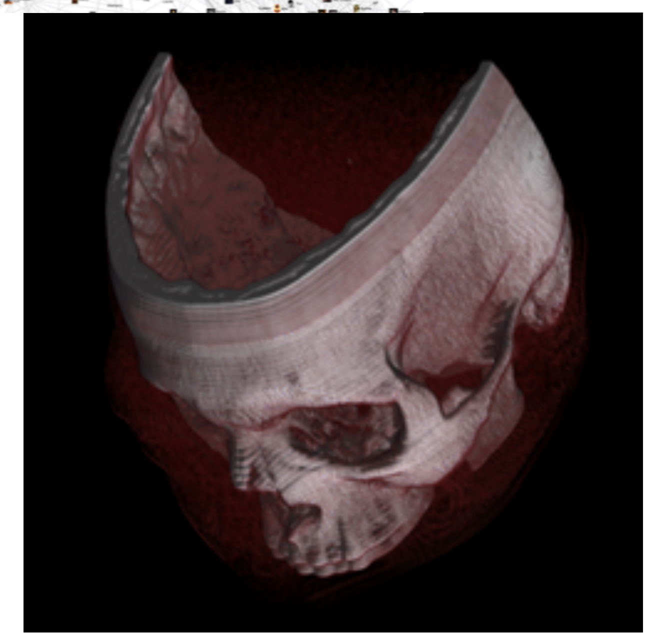
The final grade will be derived from a course average using the following weights:

- Assignments 40%
- Mid-tern Exam20%
- Final Project 40%

The Value of Visualization







The Value of Visualization

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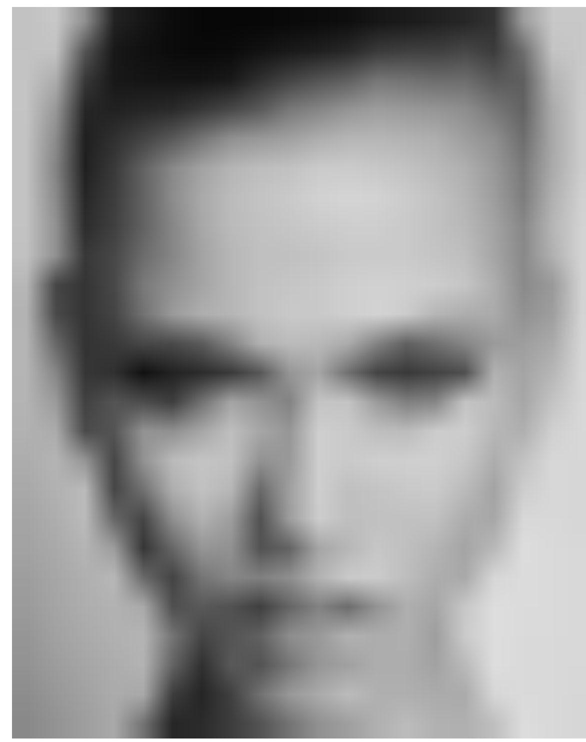

The Value of Visualization

The ability to take data—to be able to **understand** it, to **process** it, to **extract value** from it, to **visualize** it, to **communicate** it—that's going to be a hugely important skill in the next decades, ... because now we really do have **essentially free and ubiquitous data**. So the complimentary scarce factor is the ability to understand that data and extract value from it.

Hal Varian, Google's Chief Economist
The McKinsey Quarterly

What is Scientific Visualization?

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"The use of computer graphics for the analysis and presentation of computed or measured scientific data."

Ronald Peikert

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“Scientific ... visualization are branches of computer graphics and user interface design that are concerned with presenting data to users, by means of images.”

ScienceDaily

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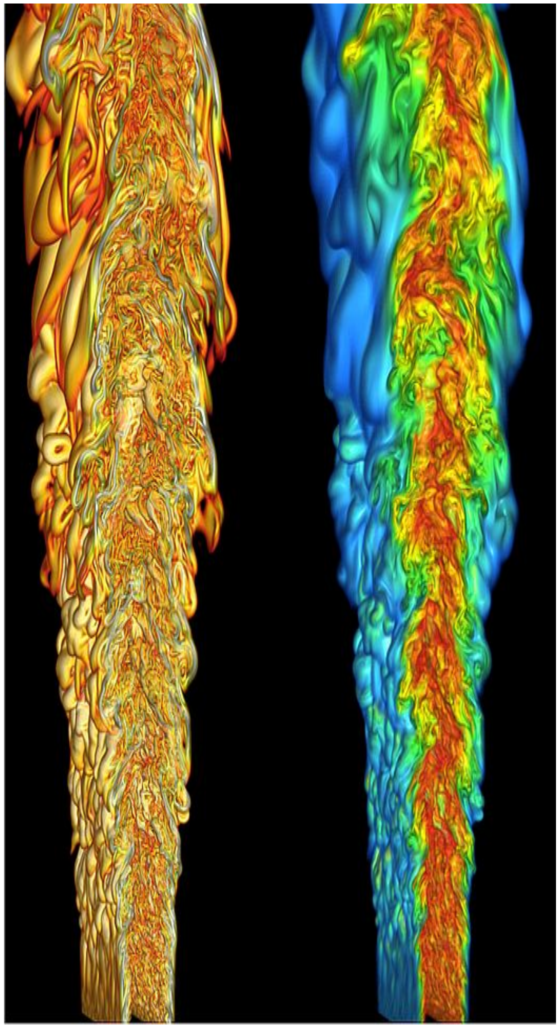
Ronald Peikert

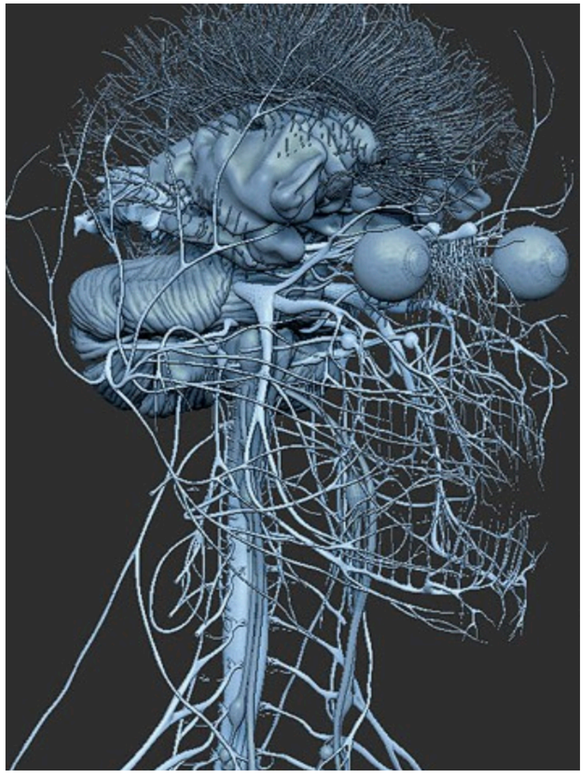
"Scientific ... visualization are branches of computer graphics and user interface design that are concerned with presenting data to users, by means of images."

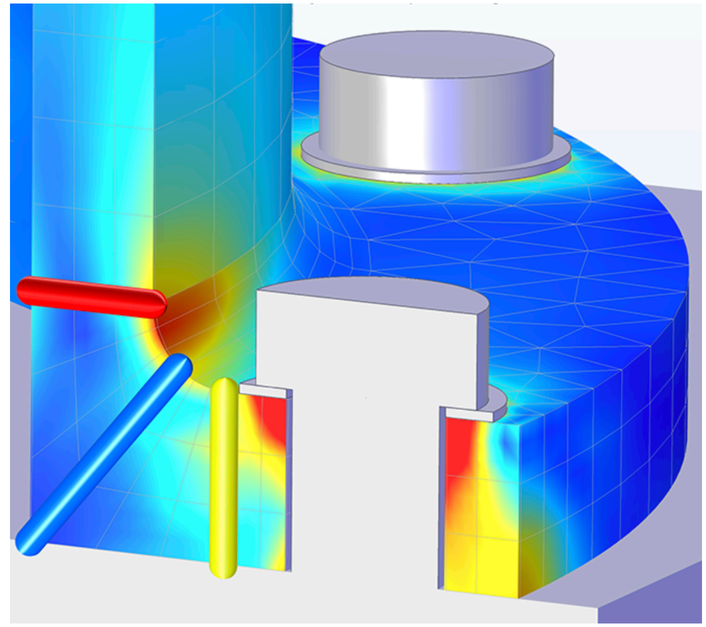
ScienceDaily

"Scientific visualization … is the representation of data graphically as a means of gaining understanding and insight into the data."

Scientific Visualization is Interdisciplinary

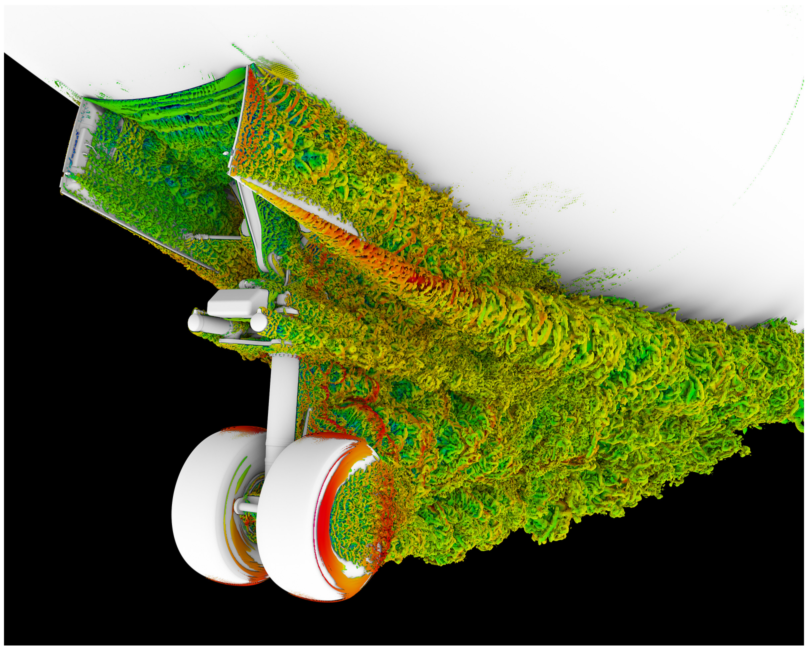


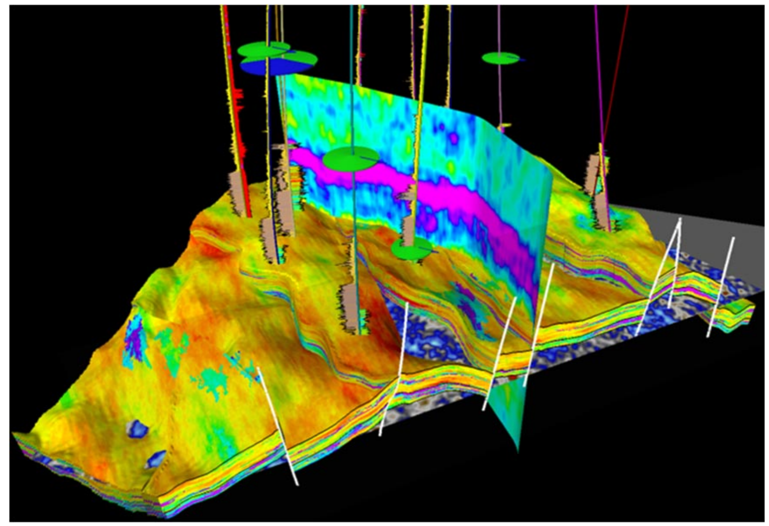


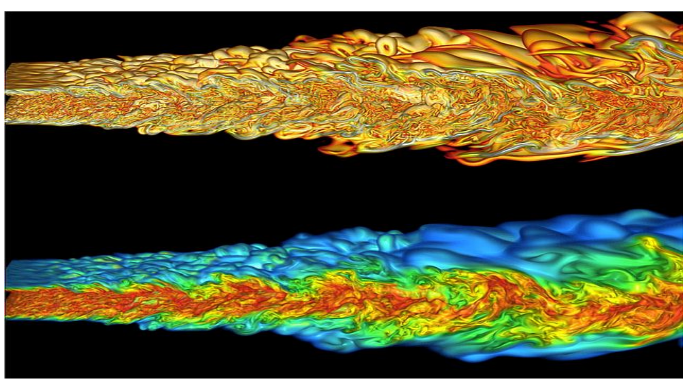


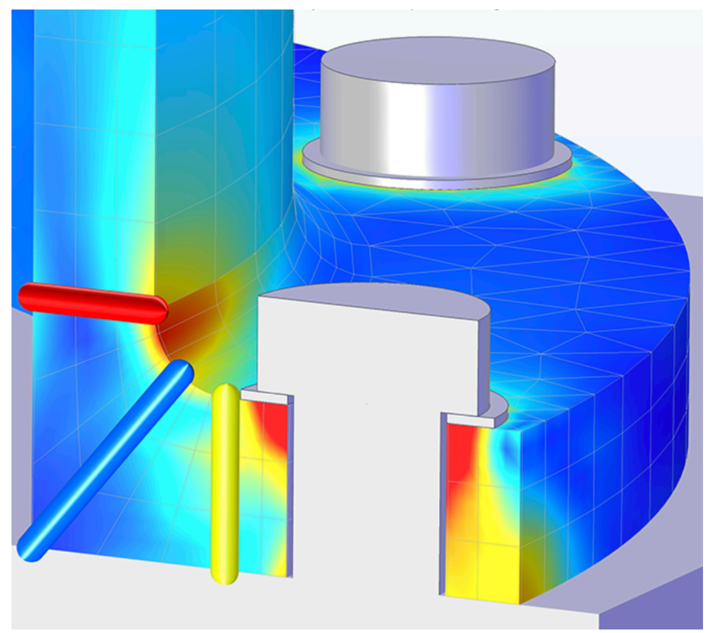
Scientific Visualization is Interdisciplinary

Engineering



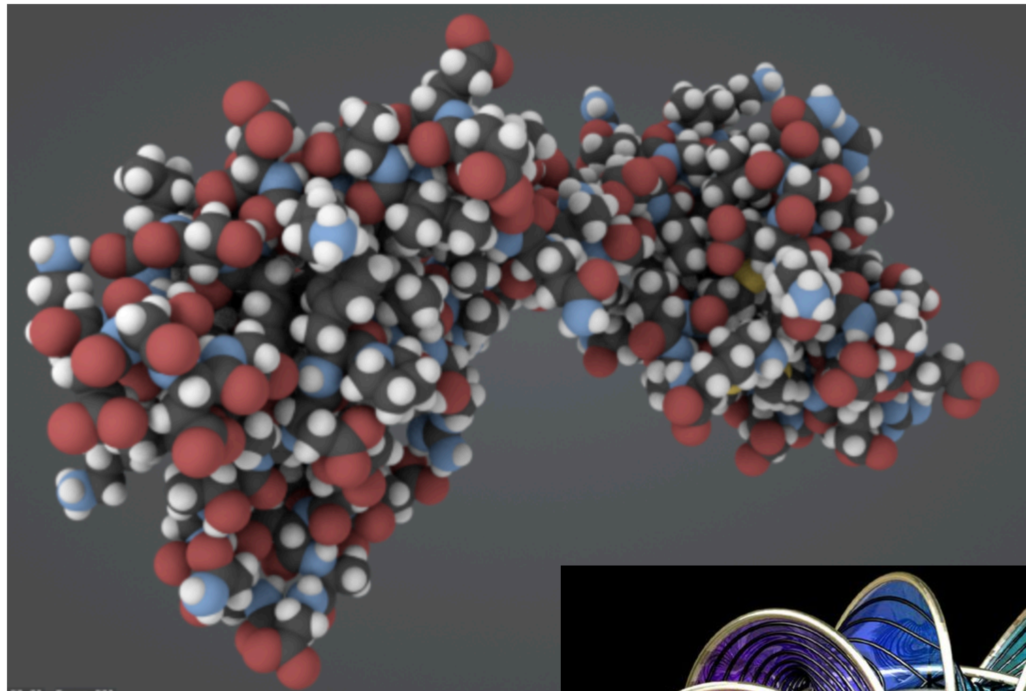






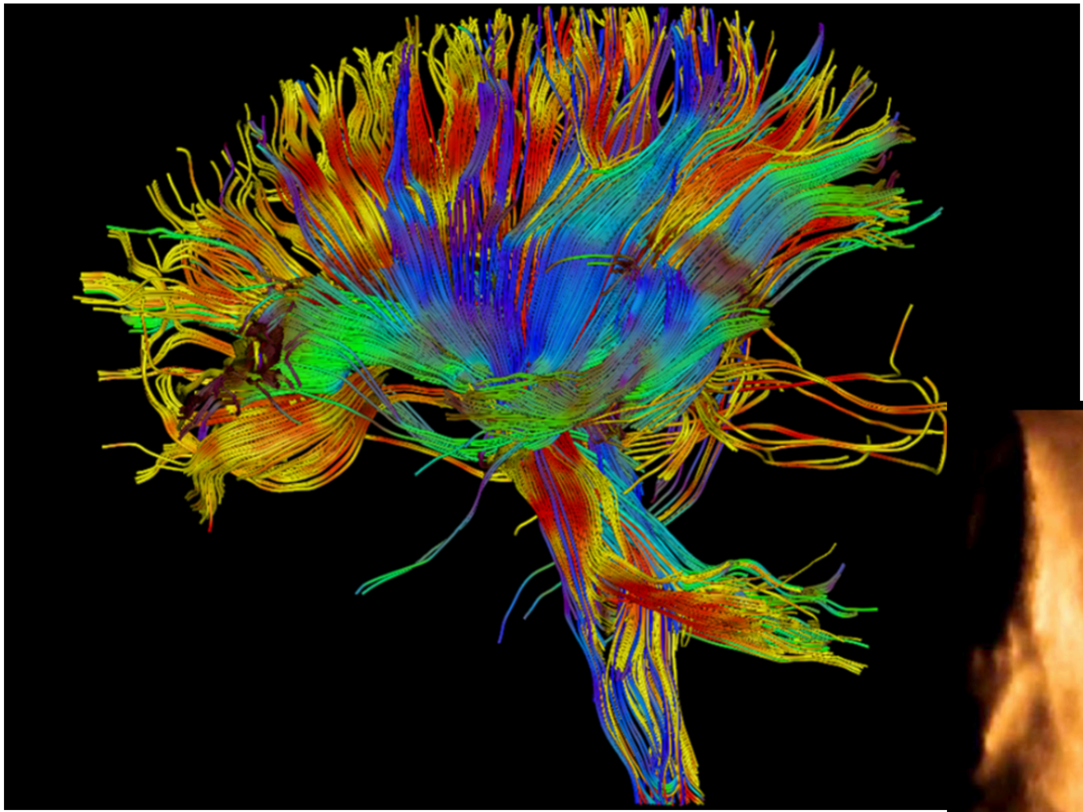
Scientific Visualization is Interdisciplinary

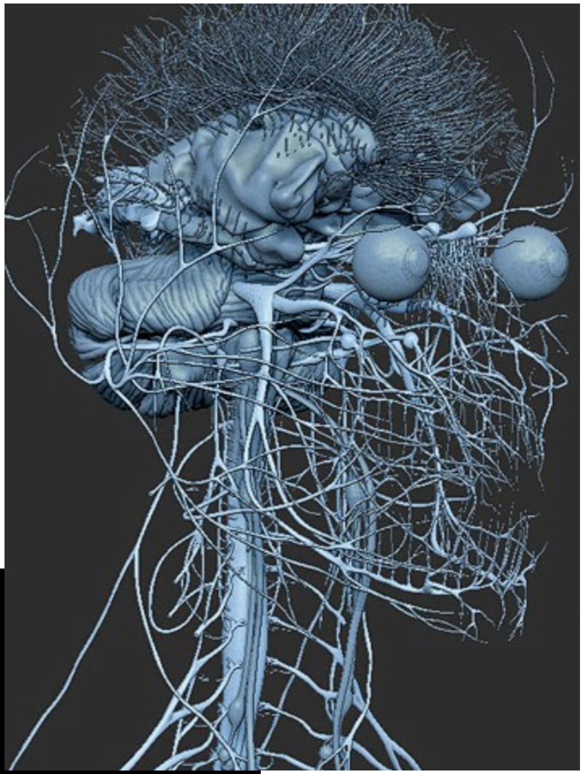
Natural Sciences

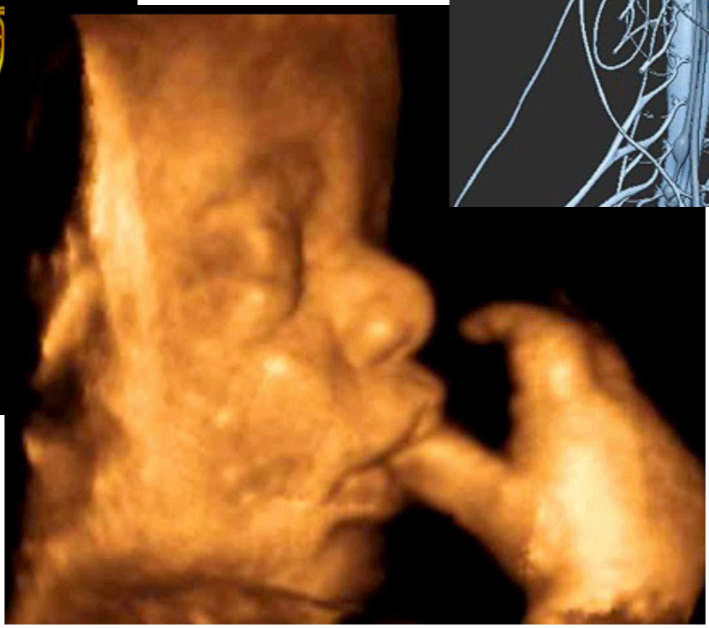


Scientific Visualization is Interdisciplinary

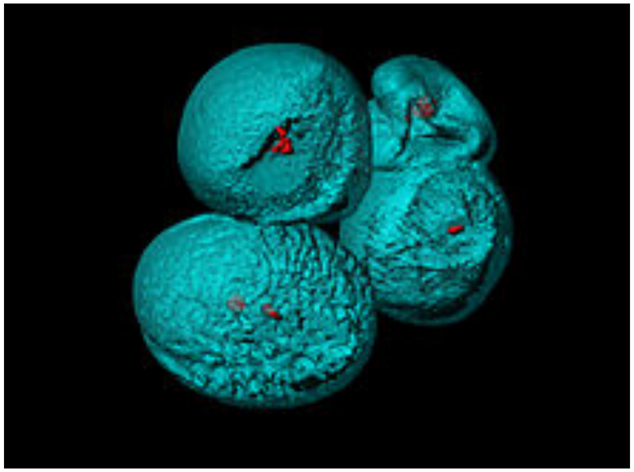
Biomedical Sciences

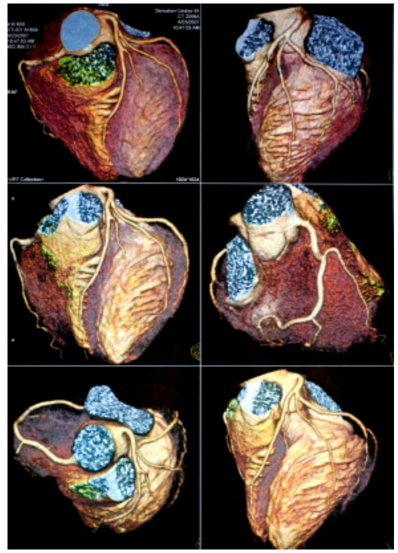


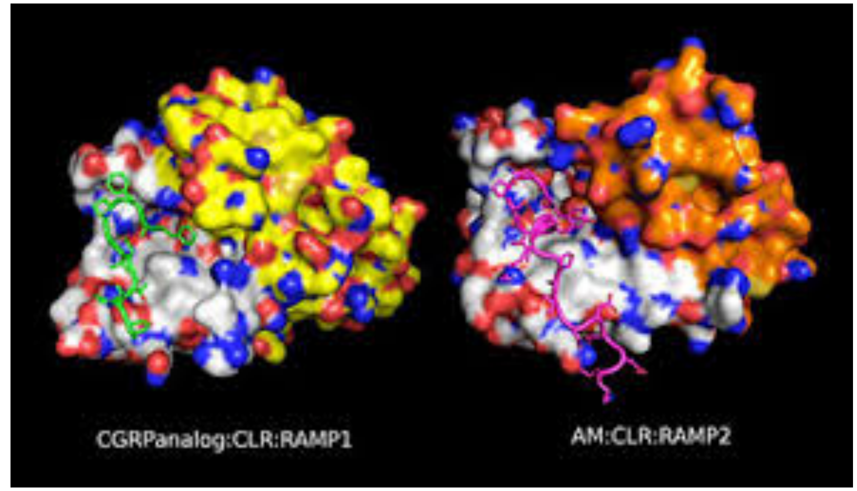


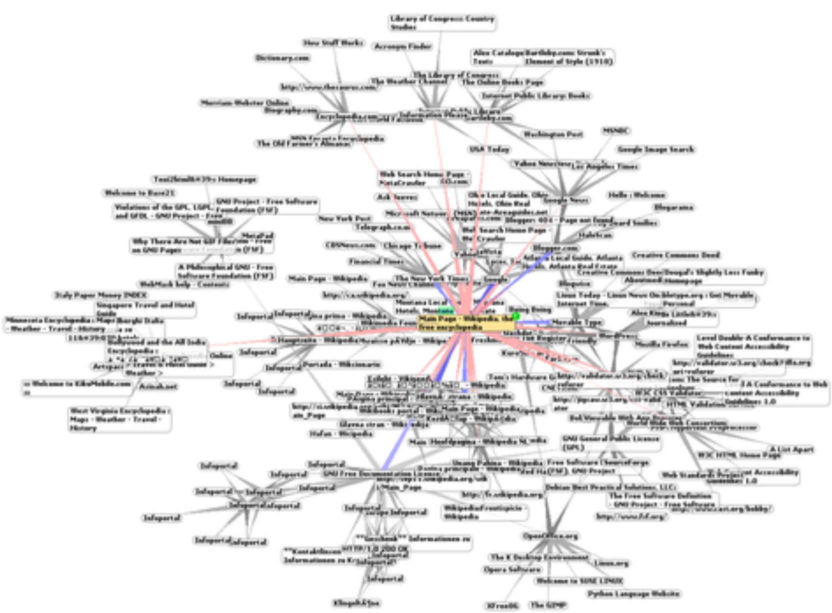


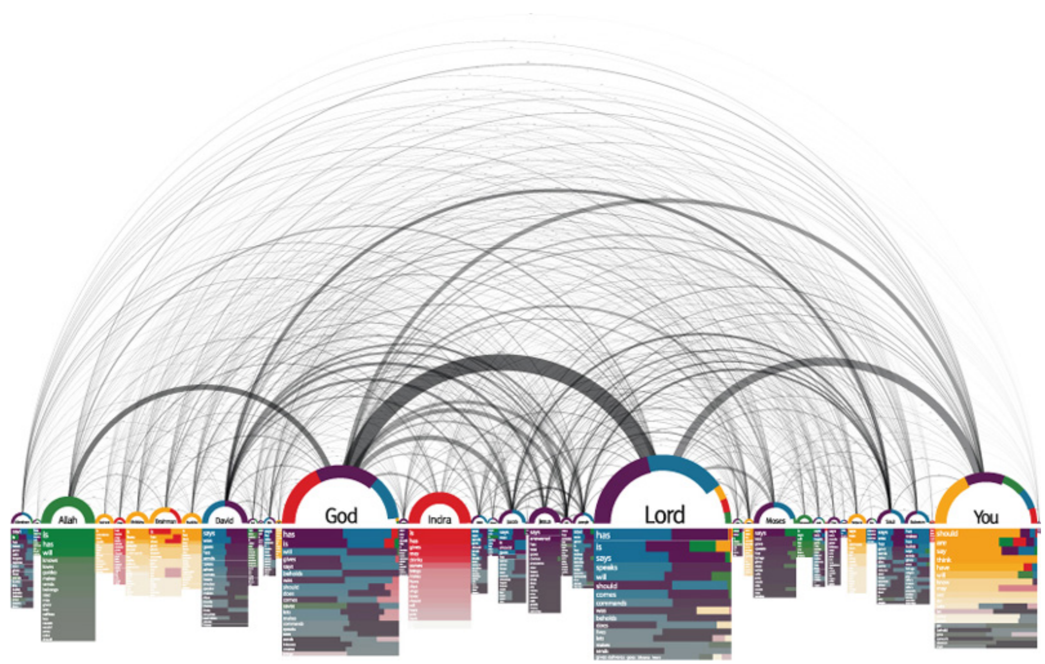
Scientific vs Information Visualization











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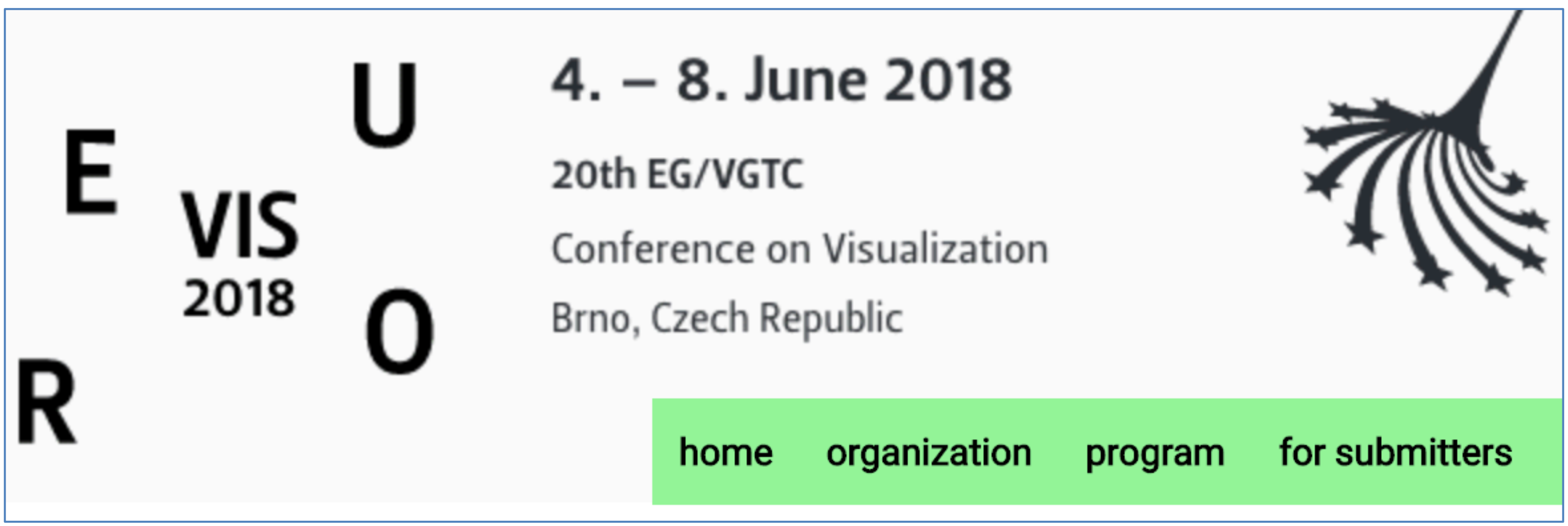

Scientific vs Information Visualization

Scientific Visualization versus Information Visualization

Henrik R. Nagel

Norwegian University of Science and Technology
Department of Computer and Information Science
hrn@idi.ntnu.no

Abstract. While Scientific Visualization techniques are used for the clarification of well-known phenomena, Information Visualization techniques are used for searching for interesting phenomena. There are therefore important differences between the two fields of research. The two fields of research are compared, but since this paper is meant for Scientific Visualization researchers, focus will be on explaining Information Visualization techniques. This paper list the main characteristics of the two fields of research, describes common Information Visualization techniques and discusses differences and similarities in the software that commonly is used in the two fields of research. . . .

1 Introduction

Some researchers mainly use visualization for finding interesting phenomenas in completely unknown data, whiles others use visualization for the confirmation or rejection of hypotheses. These two scientific communities live separate lives, with very little sharing of knowledge between them. While there naturally are important differences between the two kinds of visualization, it is the hypothesis of this paper that an understanding of both of these two ways of using visualization potentially could lead to new ways of visualizing data for the benefit of both communities.

This article therefore contains a summarization of the most important and irreconcilably differences between the ways of thinking. However, since this article is presented at a Scientific Visualization symposium, the focus will here be on Information Visualization ideas and techniques.

2 Principal Differences

Card et al. [1] defines the two forms of visualization as:

Scientific Visualization: the use of interactive visual representations of scientific data, typically physically based, to amplify cognition.

Information Visualization: the use of interactive visual representations of abstract, non-physically based data to amplify cognition.

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Information and Scientific Visualization: Separate but Equal or Happy Together at Last

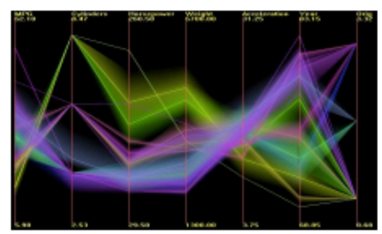
Panel Organizer & Presentor:
Theresa-Marie Rhyne, North Carolina State University

Panelists:
Melanie Tory, Simon Fraser University
Tamara Munzner, University of British Columbia
Matt Ward, Worcester Polytechnic Institute
Chris Johnson, University of Utah
David H. Laidlaw, Brown University

INTRODUCTION:

Must we continue to define a difference between information and scientific visualization? Scientific visualization evolved first in the late 1980's while information visualization matured in the mid-1990's. Scientific visualization is frequently considered to focus on the visual display of spatial data associated with scientific processes such as the bonding of molecules in computational chemistry. Information visualization examines developing visual metaphors for non-inherently spatial data such as the exploration of text-based document databases. This panel examines the effective, productive, and perhaps confusing tension between these subfields of visualization by highlighting the following issues:

- Does this tension provide useful mechanisms for advancing the global field of Visualization or is it creating confusion?
- Is there a need for a new subfield classification scheme?
- Should we continue the separate but equal approach that has been effective in the past?



Information Visualization image shown courtesy of Matt Ward of Worcester Polytechnic Institute (WPI).

IEEE Visualization 2003,
October 19-24, 2003, Seattle, Washington, USA
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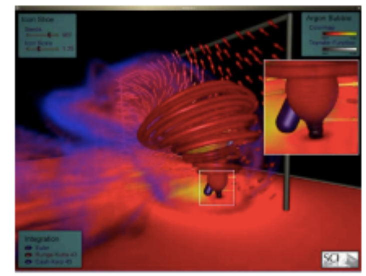

Scientific Visualization image shown courtesy of the Scientific Computing and Imaging Institute of the University of Utah.

POSITION STATEMENTS:

The Panel Organizer's Viewpoint

Theresa-Marie Rhyne:

As a visualization designer, my choices and applications of spatializations straddle both the scientific visualization and information visualization arenas. My early work in environmental sciences visualization encompassed visualizing geographically registered data from weather models. While these were scientific visualization problems, we quickly realized the importance of implementing cartographic and information visualization techniques to assist in examining environmental policy issues associated with scientific results. Today, as I work with genomic and bioinformatics researchers, I continue to float between interactive data mining visualization techniques and the interactive virtual immersion methods of scientific visualization. I think it would be clearer to genomic and other investigators if we focused on the various types of visual display and visualization methods applied rather than specifying if we are speaking in terms of information or scientific visualization. My viewpoint is that there is a need for a new subfield classification scheme. A scheme that establishes categories based on the type of spatialization techniques being applied. We can continue with the separate but equal approach that has been effective in the past but it does cause confusion when helping investigators understand how to apply visual display techniques to their specific data and information.

Scientific vs Information Visualization

Scientific Visualization versus Information Visualization

"Continuous model visualization" encompasses all visualization algorithms that use a continuous model of the data (i.e., the algorithm assumes that the phenomenon being studied is continuous, even if the data values are discrete), and is roughly analogous to "scientific visualization". "Discrete model visualization" includes visualization algorithms that use discrete data models and roughly corresponds to "information visualization".

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Information and Scientific Visualization: Separate but Equal or Happy Together at Last

Panel Organizer & Presenter:
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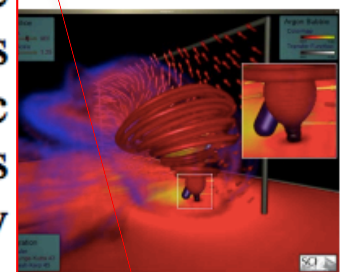

...ic Visualization image shown courtesy of the Scientific Computing and Imaging Institute of the University of Utah.

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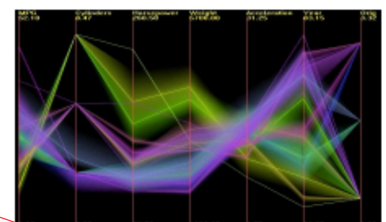

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Scientific vs Information Visualization

Information visualization, *scientific visualization* and *visual analytics* have lots of overlapping goals and techniques. There is currently no clear consensus on the boundaries between these fields, but broadly speaking the three areas can be distinguished as follows:

- Scientific visualization deals with data defined in a natural “geometric” domain (e.g. MRI data or wind flows).

- Information visualization handles more abstract data structures, such as trees or graphs.

- Visual analytics includes scientific investigation of the use of visualization in sense-making and reasoning.

Data Sources

Real world

Measurements and observation

- Medical imaging
- Geographical information systems
- Seismic data
- Astronomy

Theoretical world

Mathematical models and computer simulation

- Molecular modeling and simulation
- Computational fluid dynamics
- Structural mechanics

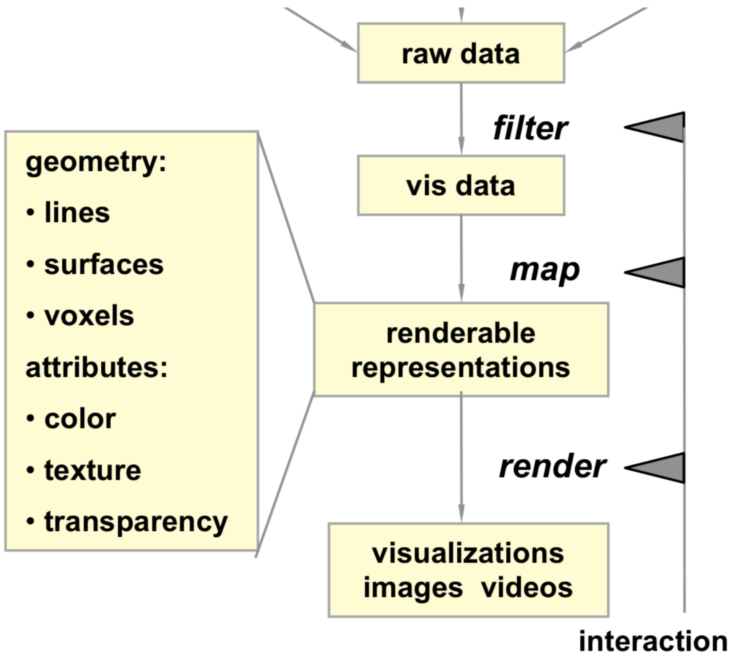
Data Types and Visualization Methods

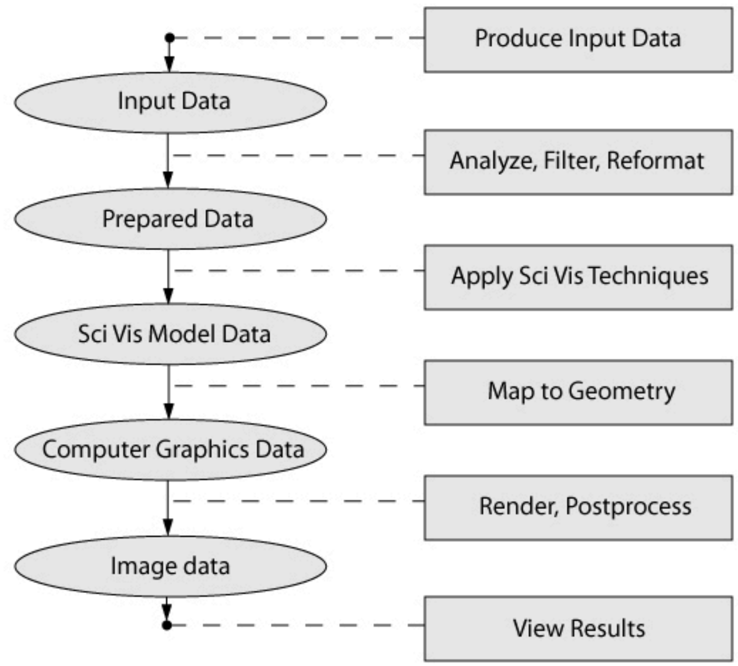
<table>
<tr><th>Data Type</th><th>Scalar</th><th>Vector</th><th>Tensor</th><th>Multivariate</th></tr>
<tr><td>1D</td><td>- Basic Plots</td><td></td><td></td><td rowspan="4">Combination of methods</td></tr>
<tr><td>2D</td><td>- Color Map
- Isoline</td><td>- LIC
- Particles
- Glyphs</td><td></td></tr>
<tr><td>3D</td><td>- Volume Rendering
- Isosurface</td><td>- LIC
- Particles
- Glyphs</td><td>- Glyphs</td></tr>
<tr><td>nD</td><td colspan="3">- Multiple 1D,2D e 3D views</td></tr>
</table>

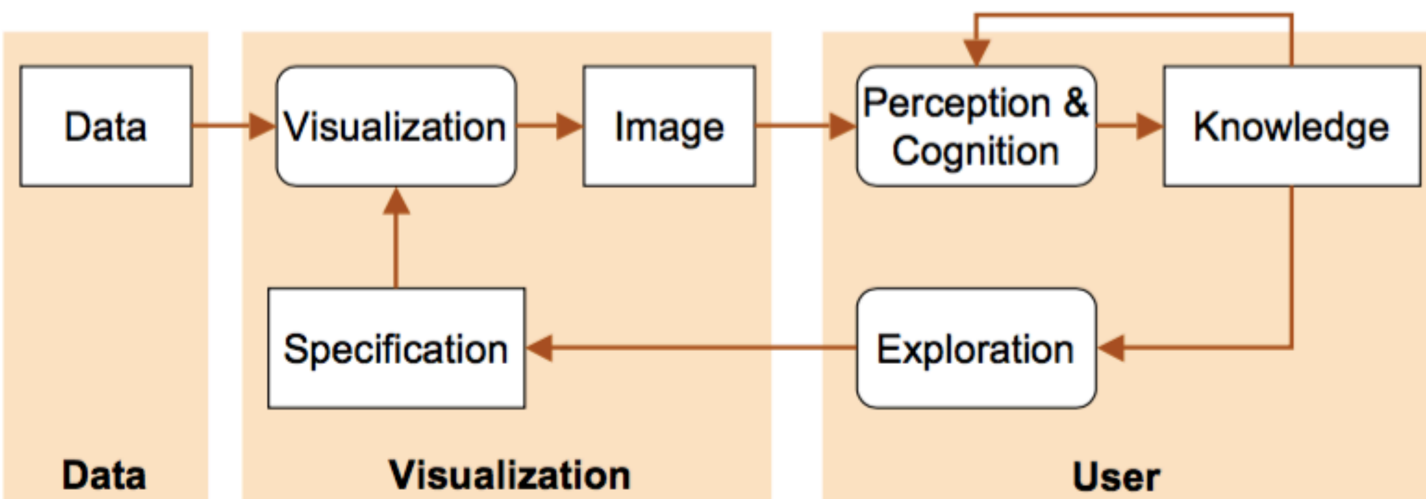
Sources of Error

- Data acquisition
  - *Device accuracy, Noise, Quantization*
- Sampling
  - *Discretization, quantization*
- Filtering
  - *Detail and high-frequency phenomena removal*
- Resampling
  - *Reduce data size, map to visualization domain*
- Interpolation
  - *Back to continuous, missing information, domain nodes*

Scientific Visualization Pipelines







J. van Wijk, IEEE Vis 2005

Scientific Visualization Pipelines

A Survey of Visualization Pipelines

Kenneth Moreland, *Member, IEEE*

Abstract—The most common abstraction used by visualization libraries and applications today is what is known as the visualization pipeline. The visualization pipeline provides a mechanism to encapsulate algorithms and then couple them together in a variety of ways. The visualization pipeline has been in existence for over twenty years, and over this time many variations and improvements have been proposed. This paper provides a literature review of the most prevalent features of visualization pipelines and some of the most recent research directions.

Index Terms—visualization pipelines, dataflow networks, event driven, push model, demand driven, pull model, central control, distributed control, pipeline executive, out-of-core streaming, temporal visualization, pipeline contracts, prioritized streaming, query-driven visualization, parallel visualization, task parallelism, pipeline parallelism, data parallelism, rendering, hybrid parallel, provenance, scheduling, in situ visualization, functional field model, MapReduce, domain specific languages

1 Introduction

The field of scientific visualization was launched with the 1987 National Science Foundation Visualization in Scientific Computing workshop report [1], and some of the first proposed frameworks used a *visualization pipeline* for managing the ingestion, transformation, display, and recording of data [2], [3]. The combination of simplicity and power makes the visualization pipeline still the most prevalent metaphor encountered today.

The visualization pipeline provides the key structure in many visualization development systems built over the years such as the Application Visualization System (AVS) [4], DataVis [5], apE [6], Iris Explorer [7], VISAGE [8], OpenDX [9], SCIRun [10], and the Visualization Toolkit (VTK) [11]. Similar pipeline structures are also extensively used in the related fields of computer graphics [2], [12], rendering shaders [13], [14], [15], and image processing [16], [17], [18], [19]. Visualization applications like ParaView [20], VisTrails [21], and Mayavi [22] allow end users to build visualization pipelines with graphical user interface representations. The visualization pipeline is also used internally in a number of other applications including VisIt [23], VolView [24], OsiriX [25], 3D Slicer [26], and BioImageXD [27].

In this paper we review the visualization pipeline. We begin with a basic description of what the visualization pipeline is and then move to advancements introduced over the years and current research.

2 Basic Visualization Pipelines

A visualization pipeline embodies a *dataflow network* in which computation is described as a collection of executable *modules* that are connected in a directed graph representing how data moves between modules. There are three types of modules: *sources*, *filters*, and *sinks*. A source module produces data that it makes available through an *output*. File readers and synthetic data generators are typical source modules. A sink module accepts data through an *input* and performs an operation with no further result (as far as the pipeline is concerned). Typical sinks are file writers and rendering modules that provide images to a user interface. A filter module has at least one input from which it transforms data and provides results through at least one output.

The intention is to encapsulate algorithms in interchangeable source, filter, and sink modules with generic connection ports (inputs and outputs). An output from one module can be connected to the input from another module such that the results of one algorithm become the inputs to another algorithm. These connected modules form a *pipeline*. Fig. 1 demonstrates a simple but common pipeline featuring a file reader (source), an isosurface generator [28] (filter), and an image renderer (sink).

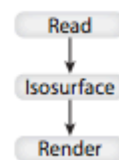


Fig. 1: A simple visualization pipeline.

Pipeline modules are highly interchangeable. Any two modules can be connected so long as the data in the output is compatible with the expected data of the downstream input. Pipelines can be arbitrarily deep. Pipelines can also branch. A *fan out* occurs when the output of one module is connected to the inputs of multiple other modules. A *fan in* occurs when a module accepts multiple inputs that can come from separate module outputs. Fig. 2 demonstrates a pipeline with branching.

These diagrams are typical representations of pipeline structure: blocks representing modules connected by arrows representing the direction in which data flows. In Fig. 1 and Fig. 2, data clearly originates in the read module and terminates in the render module. However, keep in mind that this is a logical flow of data. As documented later, data and control can flow in a variety of ways through the network.

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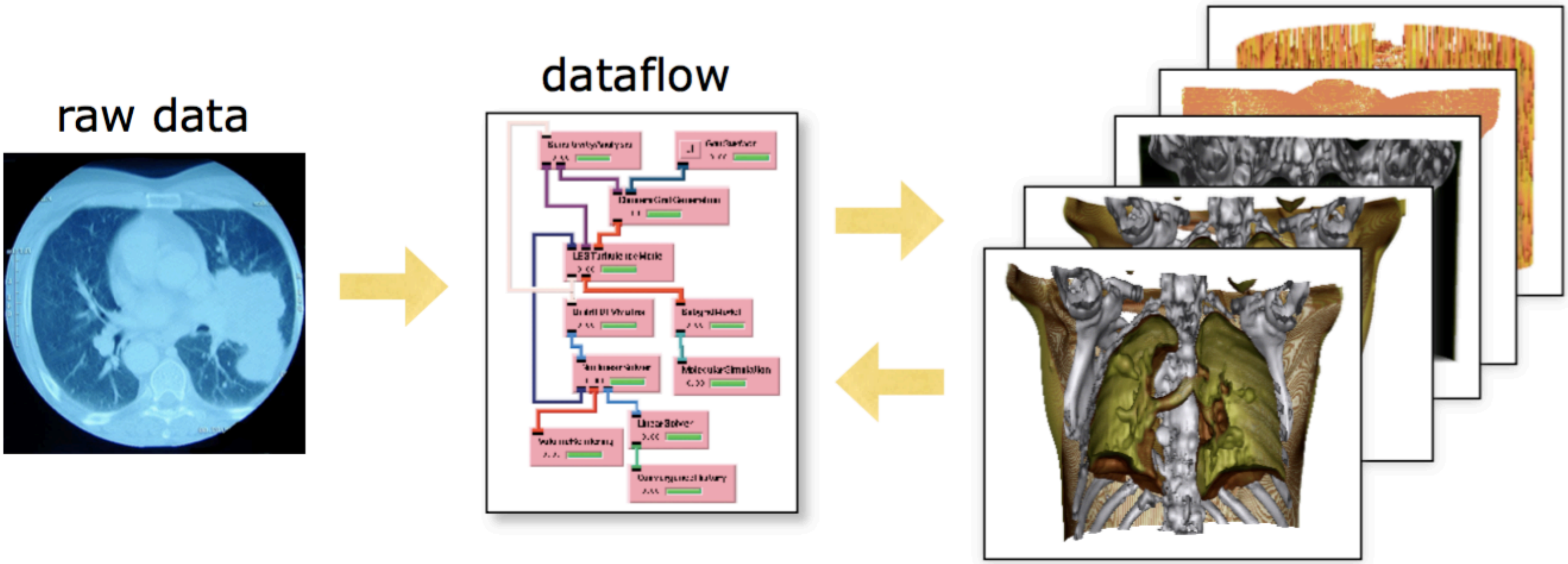
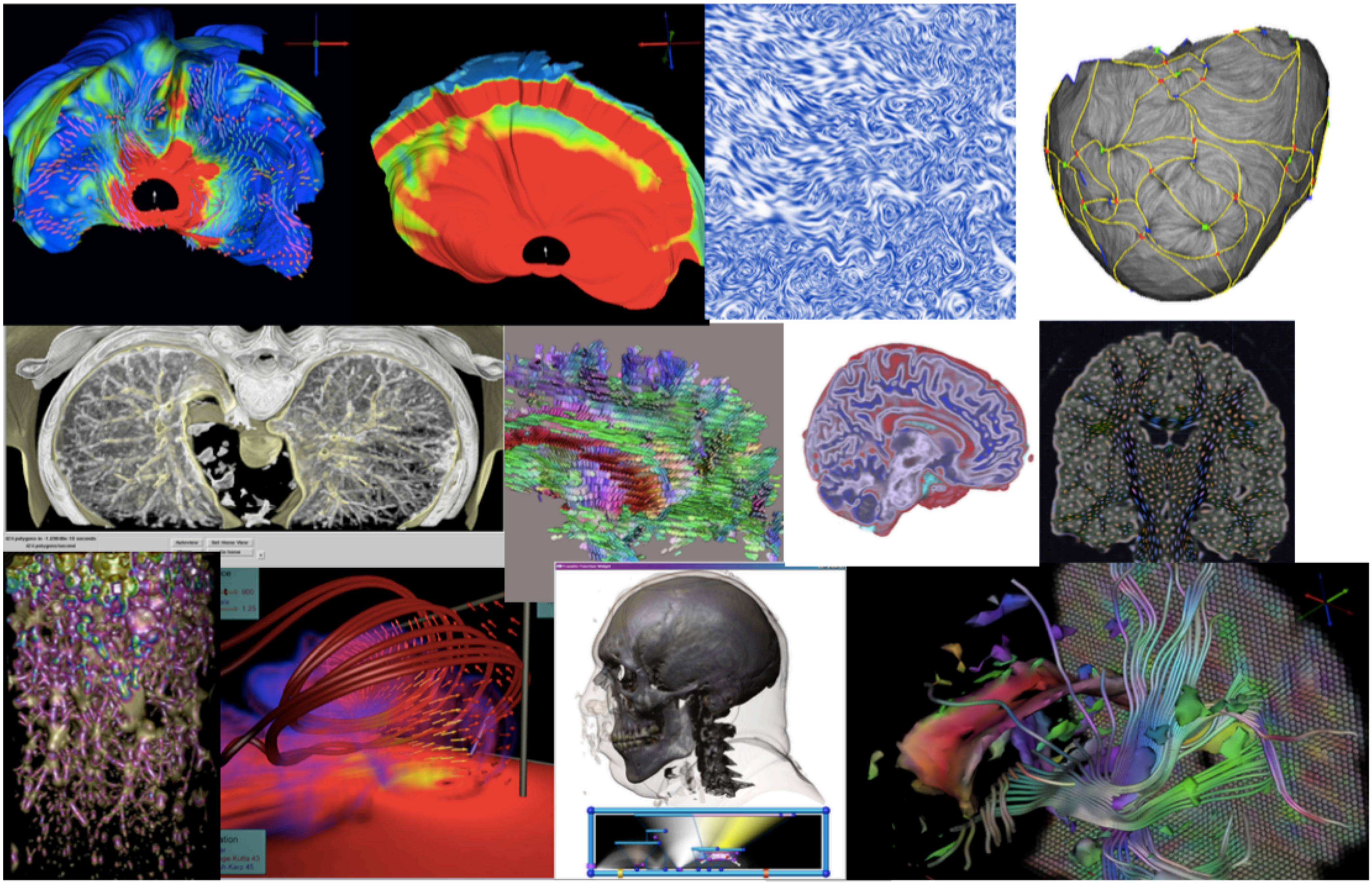
Scientific Visualization Pipelines

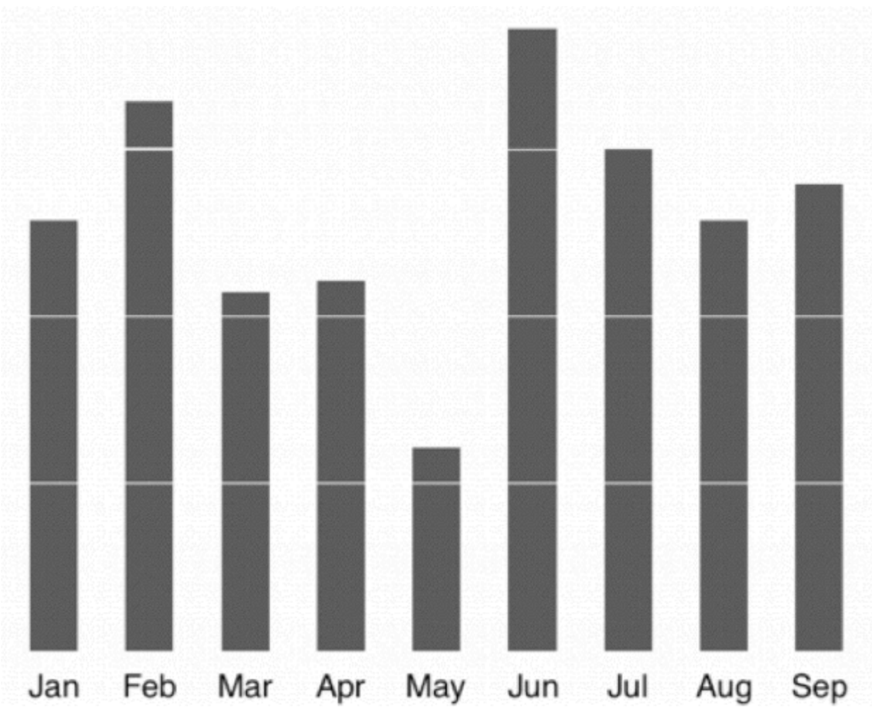


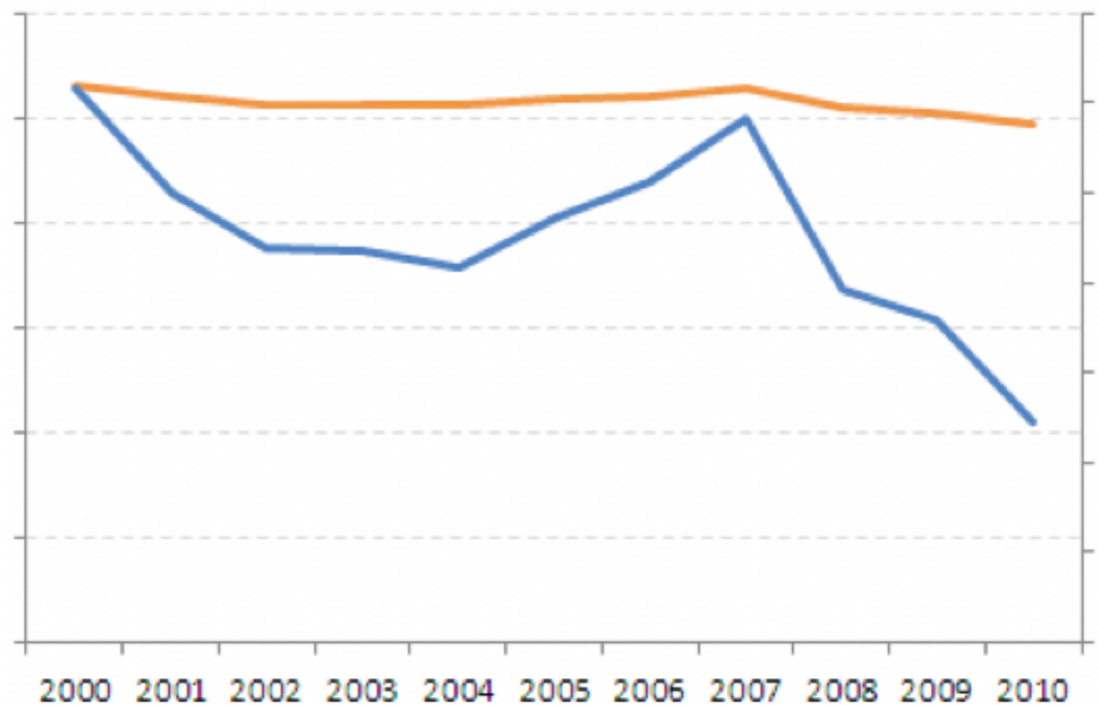
Scientific Visualization Techniques



Scientific Visualization Techniques

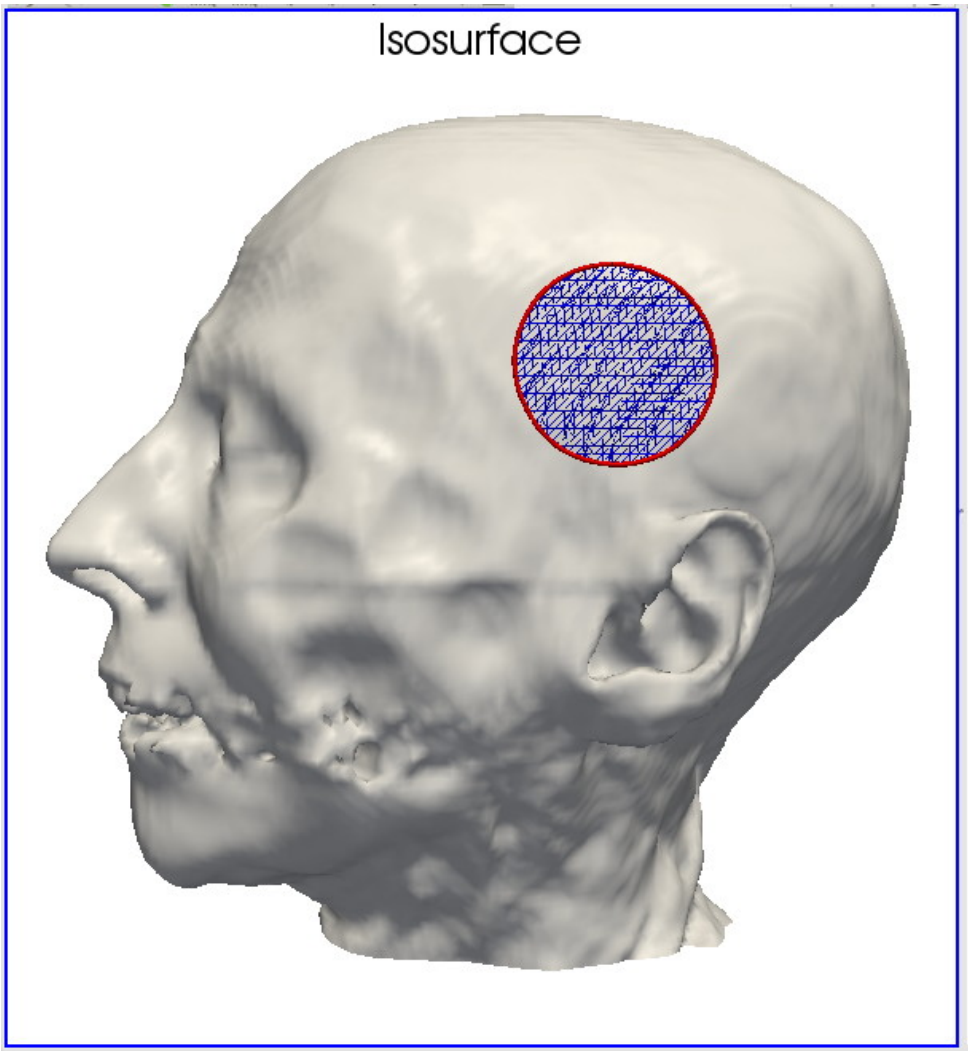
Basic Plots

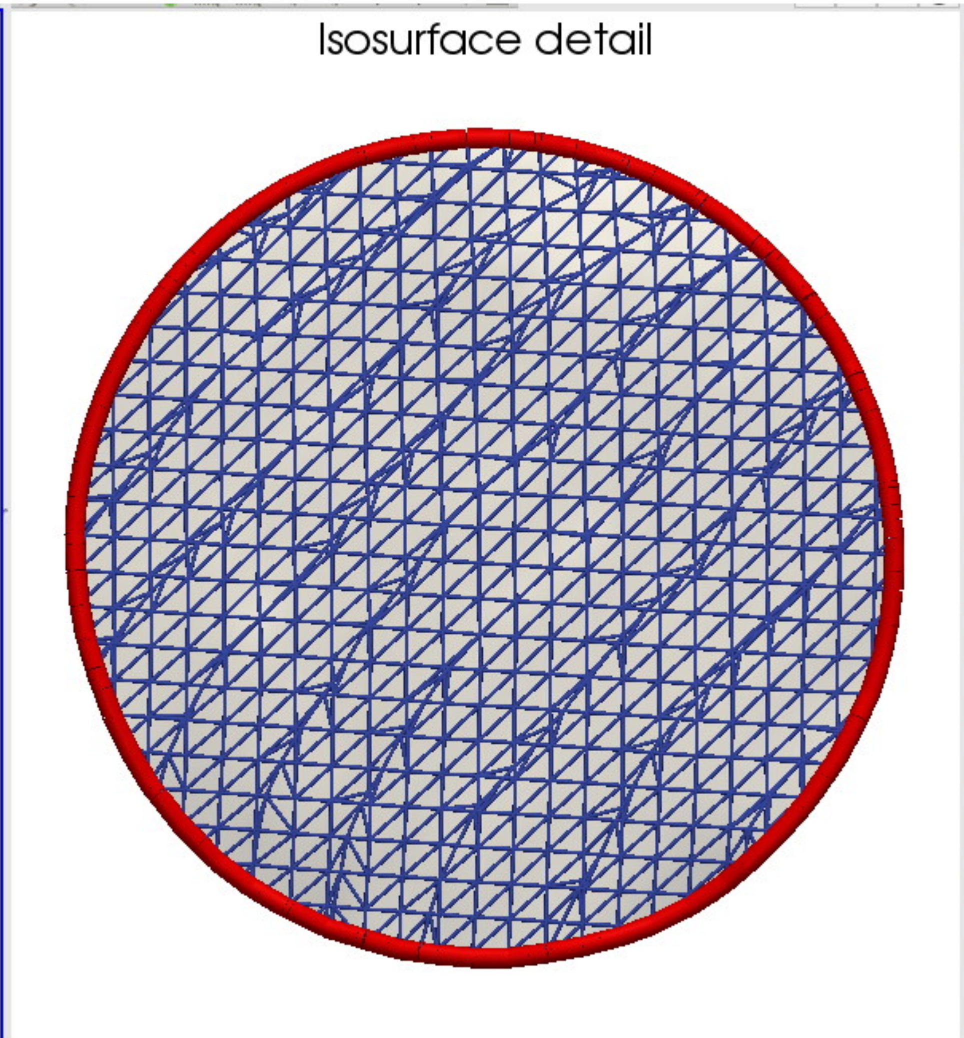




Scientific Visualization Techniques

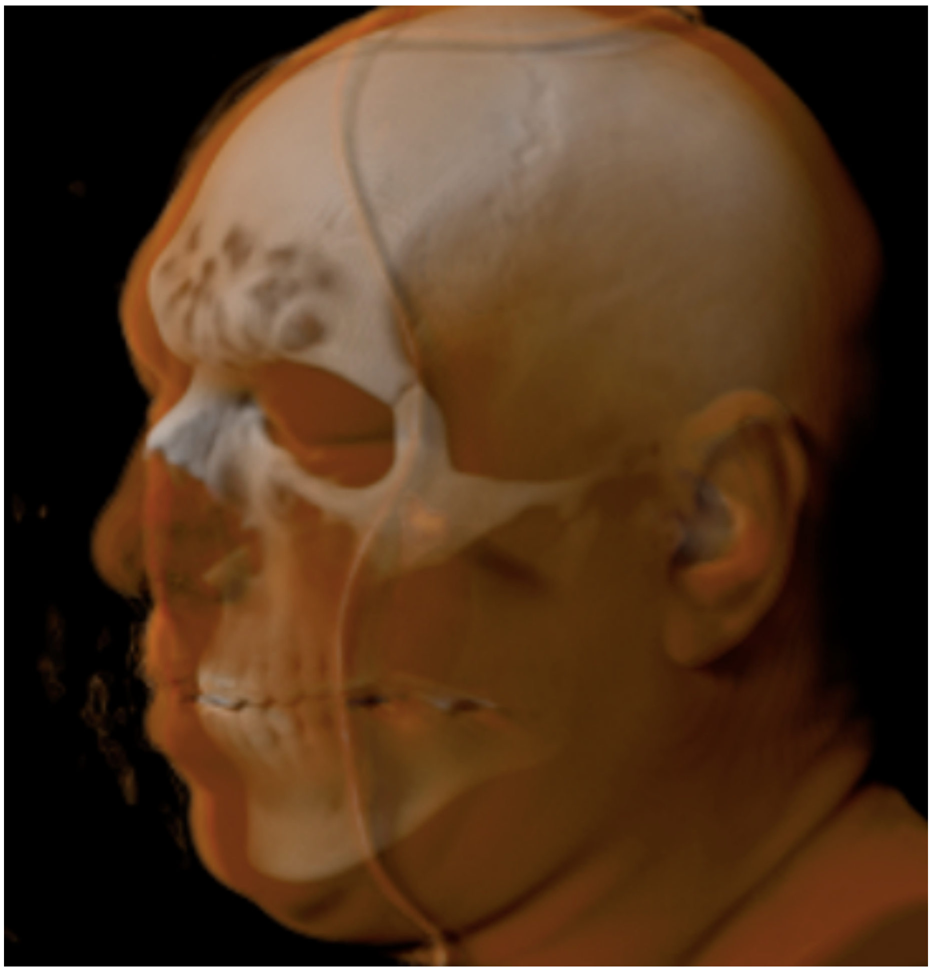
Contouring and Isosurfaces

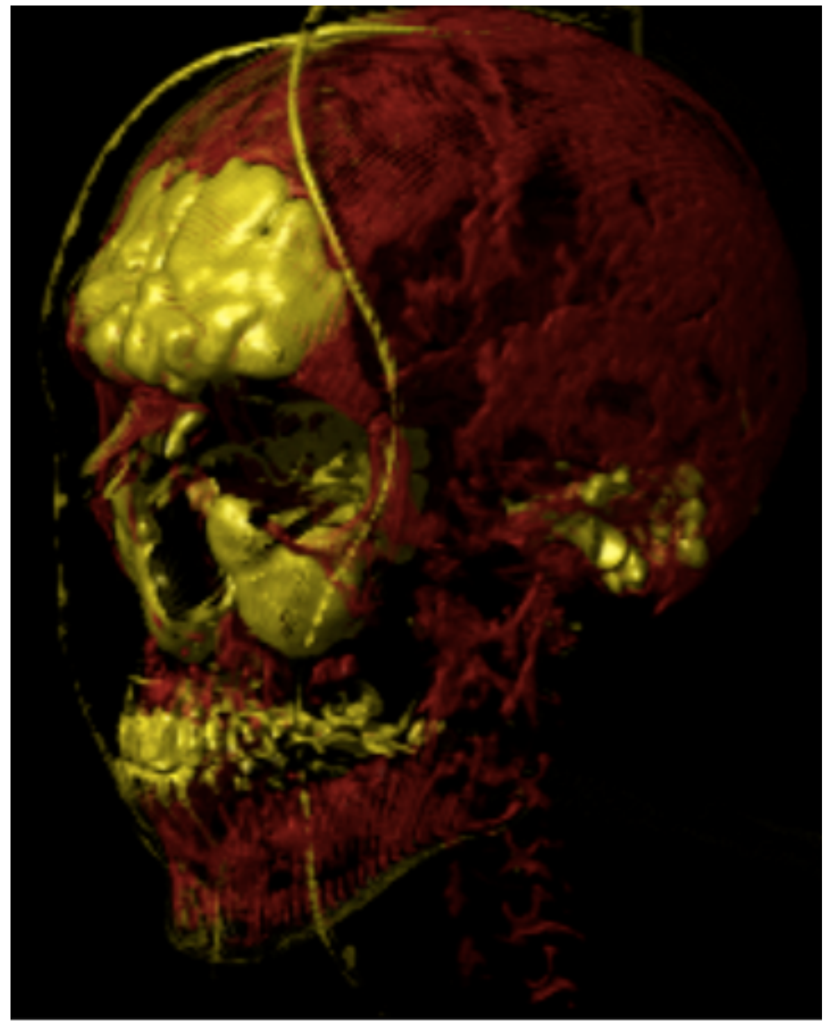




Scientific Visualization Techniques

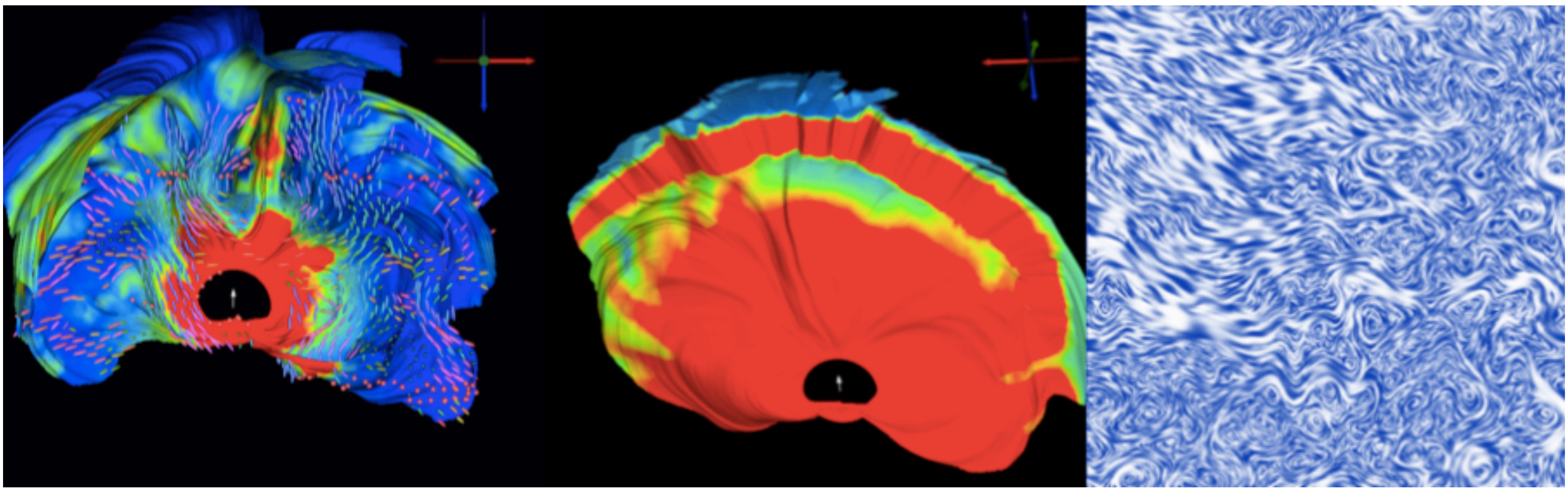
Volume Rendering





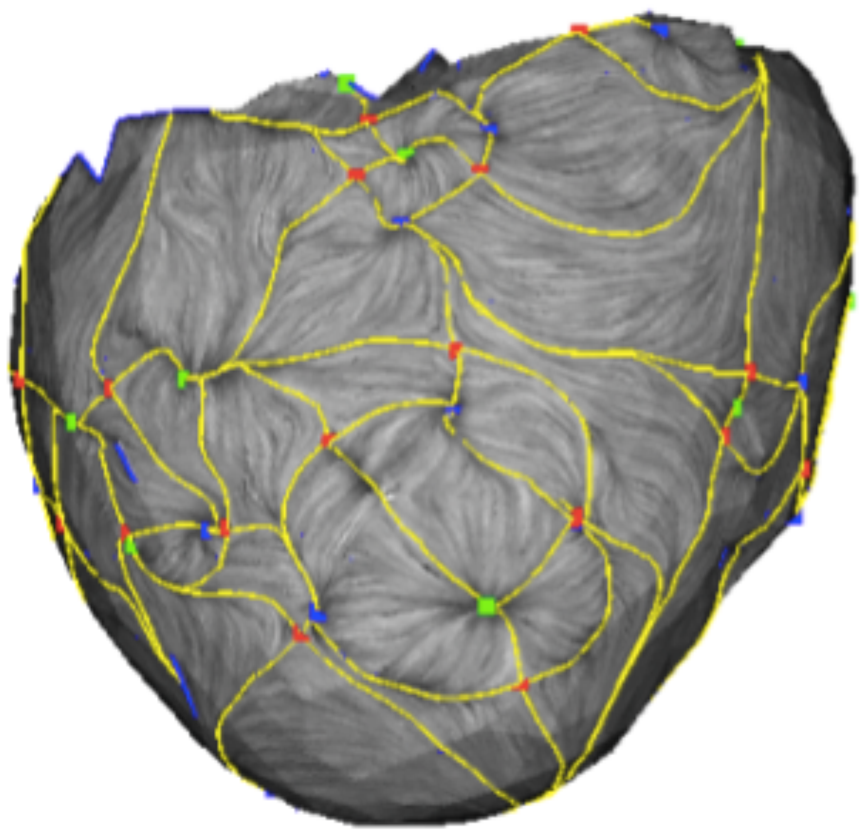
Scientific Visualization Techniques

Vector and Tensor Fields



Scientific Visualization Techniques

Topology-based

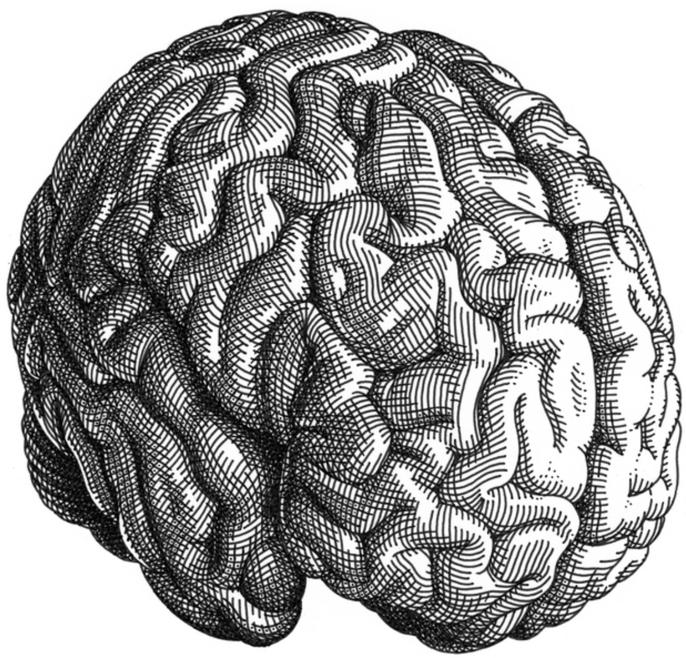


Scientific Visualization Systems and Packages

- VTK/Paraview (General Purpose)
- Covise (Numerical Simulation)
- Tecplot (Reservoir)

Other Related Topics

- Illustrative visualization
- Multiscale, multiresolution methods
- Uncertainty visualization
- Out-of-core algorithms



The Main Venues

Conferences

- IEEE Visualization – SciVis track
- EuroVis

Journals

- IEEE Transactions on Visualization and Computer Graphics
- Computer Graphics Forum