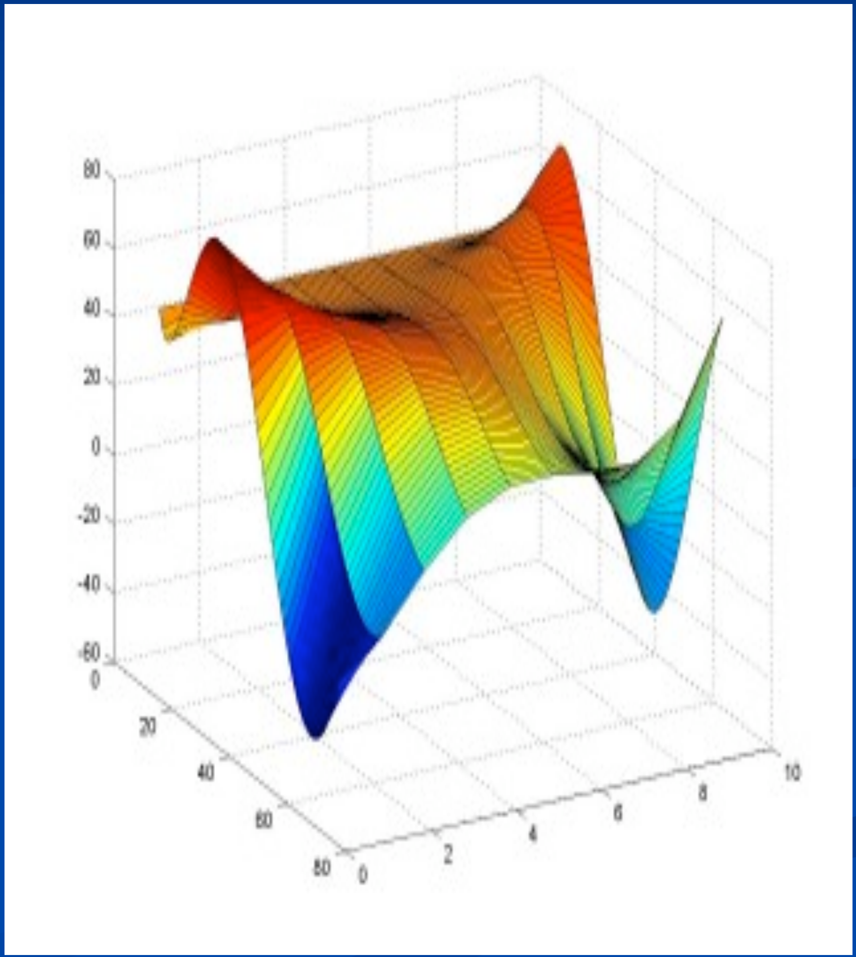
Scientific Visualization

- CS 521
- Spring '05
- Eli, Drew, Shaz



Introduction

- SciVis utilizes computer graphics, image processing, signal processing as techniques to analyze numerical data.

- It makes it much easier to understand results of complex numerical data analysis

- The visualization helps scientists to interact and investigate with certain aspects of the data.

What it is?

- The methodology of quickly and effectively representing data.

- Humans perceive better than machines, and machines calculate much more consistently and accurately.

- It is a combination of graphics capabilities in the 21st century with human perception.

The Need

- Ability to deal with the randomness included in natures equations.
- The larger amounts of test data capability, results of which are normally harder to see.
- The largest test data available to us is one nature provides us with.

Quality Vs. Quantity

- Quantity
  - Provides a bigger picture
  - Play with the whole data set
- Quality
  - Ability to slice a subset of the data set.
  - Detail – oriented

History

- Three stages of mdmv (multidimensional multivariate visualization) development
  - Searching stage (1782 – 1976)
  - Awakening stage (1977 – 1985)
  - Discovery stage (1987 – 1991)

Searching stage

- Mdmv was to be studies long before computer science by statisticians and psychologists

- All studies were in 2D xy displays due to lack of technology.

Awakening stage

- Tukey came out with data analysis methods

- 2D and 3D spatial data was commonly studied during the time.

- It was not just a tool anymore but a way of understanding how to decode data

Discovery Stage

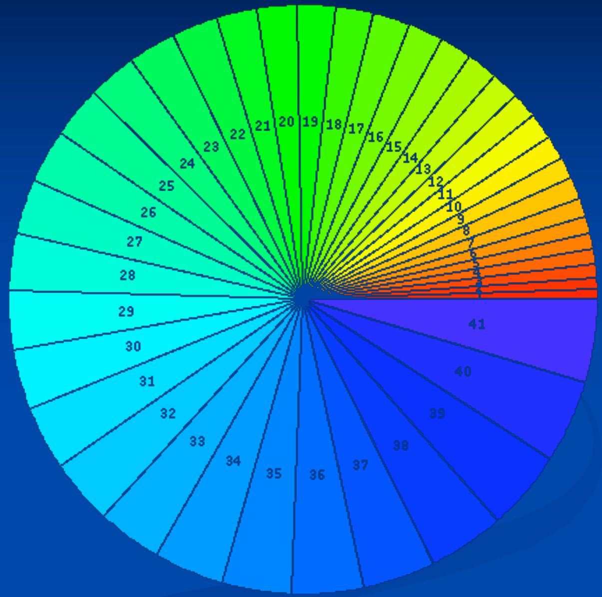
- Moved away from just data analysis to very high graphical visualizations which required a lot of computation power.
- Virtual reality brought new meaning to visualization techniques.
- NFS declared the need for 2D/3D spatial visualization.

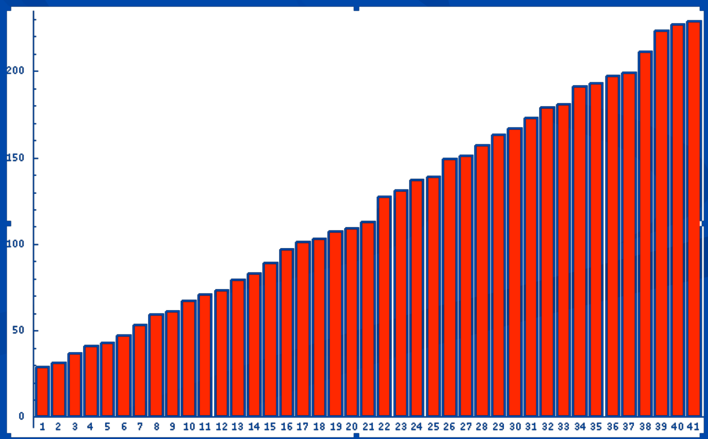
Breakdown

- Independent variable – Dimension
- Dependent variable – Variate
- Equation –
  - $Y = f(x)$
  - Y is dependent on X

2D Visualization Example

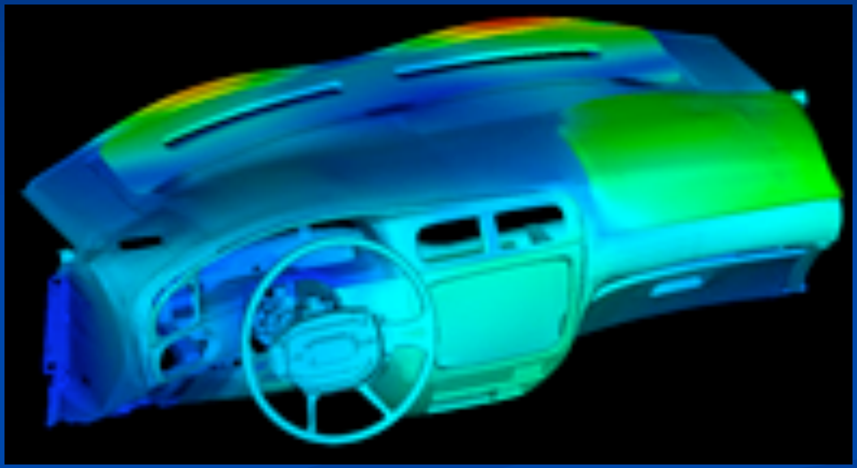
- Example of 2D visualization (charts) most commonly used in business applications.

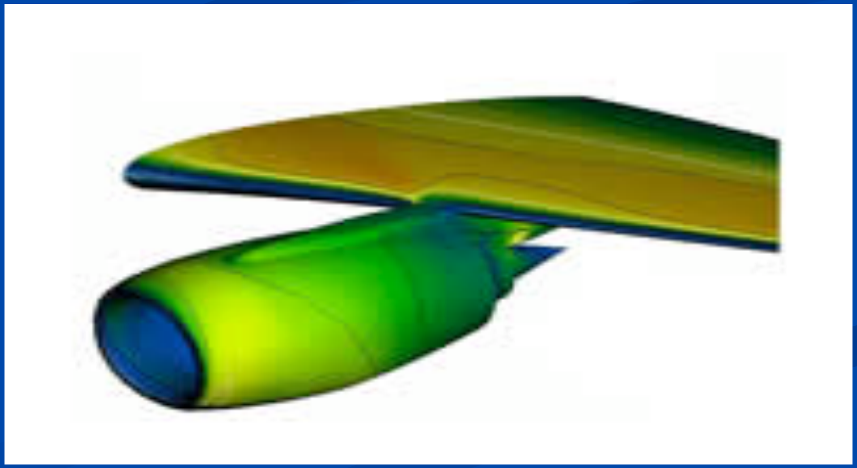




3D Visualization Example

- Reynard Motorsport Engineers recognized as leader in Formula 1 and Indy car design use Ensight to study airflows.
- Voith hydro to design more efficient hydroelectric turbines less harmful to fish.





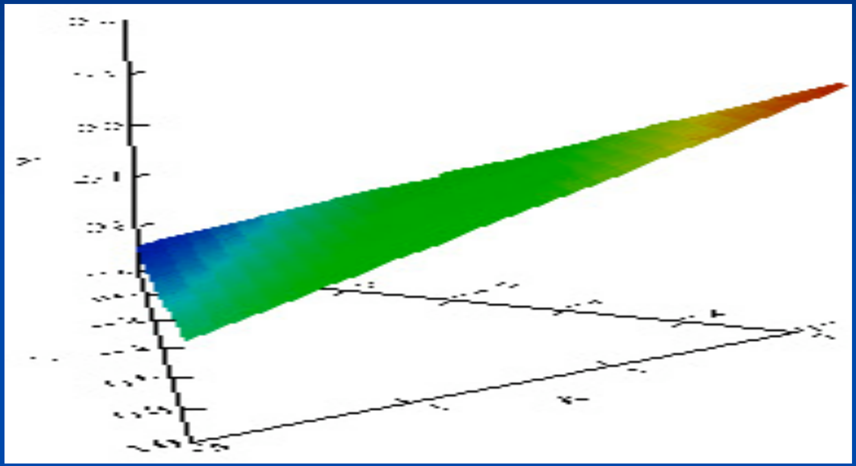
Motivations

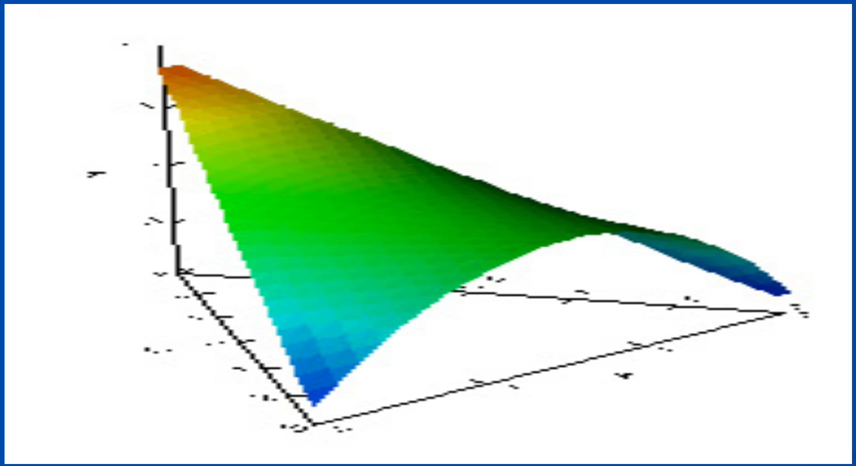
- The availability of increasingly powerful computers with extremely fast internal and external memory.
- Compresses a lot of data into one picture (data browsing).
- Reveals co-relations between different quantities both in space and time.
- Possible to view data selectively and interactively in 'real time'.

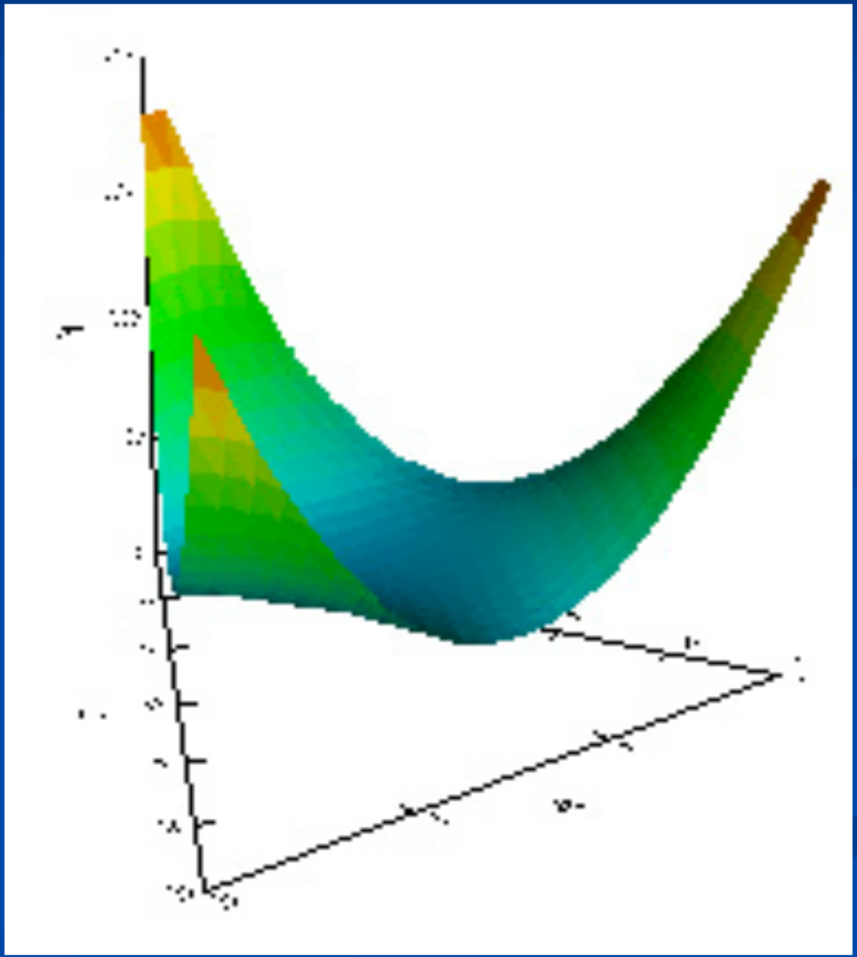
Foundations

- Spatial – oriented
  - Still graphs used, all relevant data is displayed at the same time in a given space
  - Multiple view vs. multiple symbol
    - Multiple view – one display panel shows values of multiple variables simultaneously
    - Multiple symbol – Only one symbol is used but conditional relationships are shown in multiple panels.

Example







Foundations

- Temporal Oriented
  - Also known as Kinematic displays (Tukey and Tukey 1988)
  - Variations across time are utilized to depict higher dimensions instead of using all variables within given space and time.

References

- http://pareonline.net/getvn.asp?v=8&n=17
- http://www.cse.ohio-state.edu/~crawfis/cis694L/
- SciVis presentation of spring '03 CS521
- http://www.ceintl.com/industries/industries.html

Current Visualization Software

NCL, Amira, and OpenDX

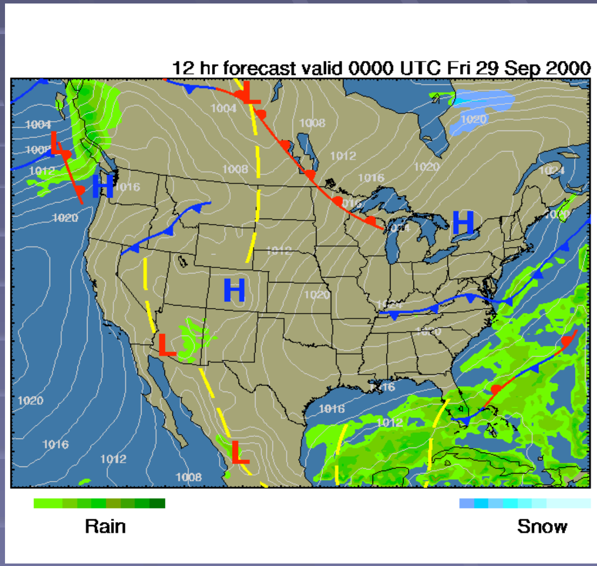
By Drew Brumm

What is NCL

- NCAR Command Language.
  - Programming Language designed specifically for the access, analysis, and visualization of data.
- NCL Modes
  - Interactive mode
    - Where each line is interpreted as it is entered into the computer
  - Batch Mode
    - Runs complete downloaded scripts.

NCL Cont.

- Has Three Main Functionalities
  - File input and output
  - Data processing
  - Graphical display



- Common Programming Features
  - Includes types, Variables, Operators
  - Expressions, Conditional Statements
  - Loops, Functions and procedures.

NCL Support

- NCL has 1, 2, 3-dimensional interpolation, approximation, and regridding.
- Supports C and Fortran external routines
- Has over 400 built in functions for processing and manipulating data.
- Similar to Matlab or IDL

What is Amira

- Advanced Visualization, Data Analysis, Geometric Reconstruction Tools.
- Has automatic and interactive segmentation tools
  - Slices into full picture
- Reconstruction algorithms
  - Takes slices and makes 3-D model without some of the unwanted details.

Amira Cont.

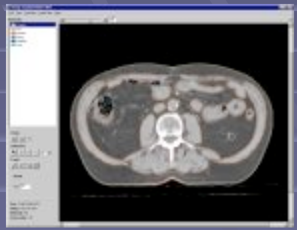
- Data Import
  - 3D image formats: DICOM, Analyze, AVS, …etc
  - Advanced import, slice sorting and grouping
- Slicing and Clipping
  - Semi-transparent slice display
  - Interactive clipping planes
- Surface Rendering
  - Display of partial surfaces
  - Overlay of opaque (bone) with semi transparent (skin or muscle)

Amira Cont.

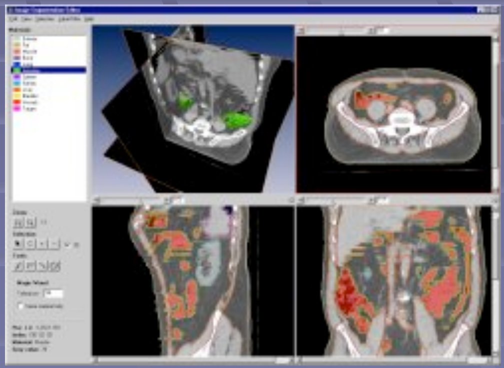
- Viewing and Navigation.
  - Multiple independent or synchronized viewer windows
  - Viewpoints outside or inside of object
- Large Data Sets
  - Uses Fast interactive OpenGL rendering latest graphics hardware
  - Quick access to a region of interest with large datasets.
- Surface Reconstruction
  - 3D image has been segmented creates the corresponding polygonal surface model

Amira Medical

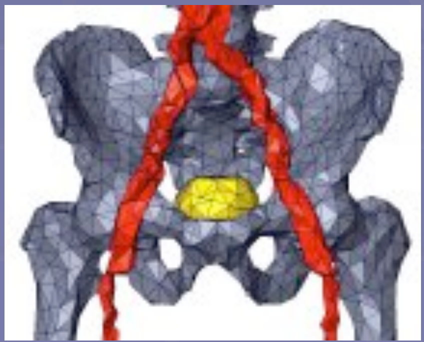
- Amira is tailored for Biology and Medicine
  - Step 1: Starts by entering data using DICOM import features.



  - Step 2: Automatic segmentation

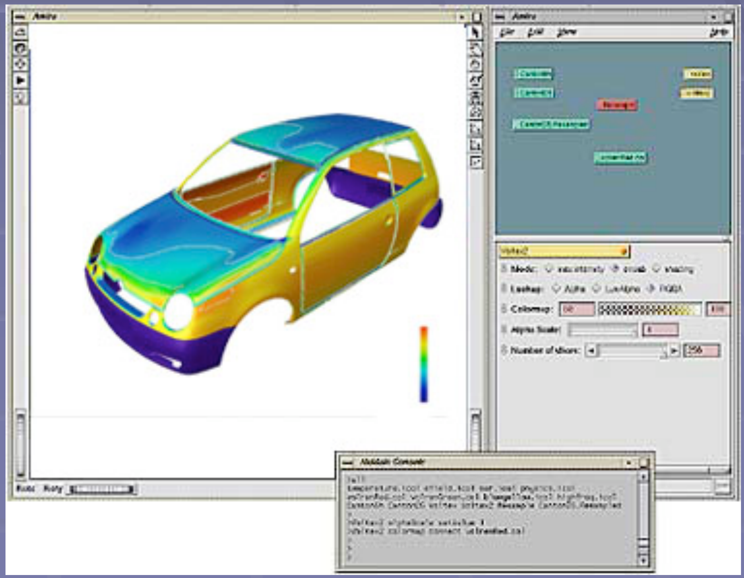


  - Step 3: Segmentation editor regions of interest are interactively marked and labeled.
  - Step 4: Form 3D model generated with ability to peal away layers or clear and enhance images



Amira Engineering

- Works for Engineering Fields as Well
  - Numerical simulations
  - Fluid dynamics, Hydrodynamics
  - Crash Analysis and simulation
  - Physics, Electromagnetism
  - Environmental, Energy
  - Ocean Weather Atmosphere



What is OpenDX

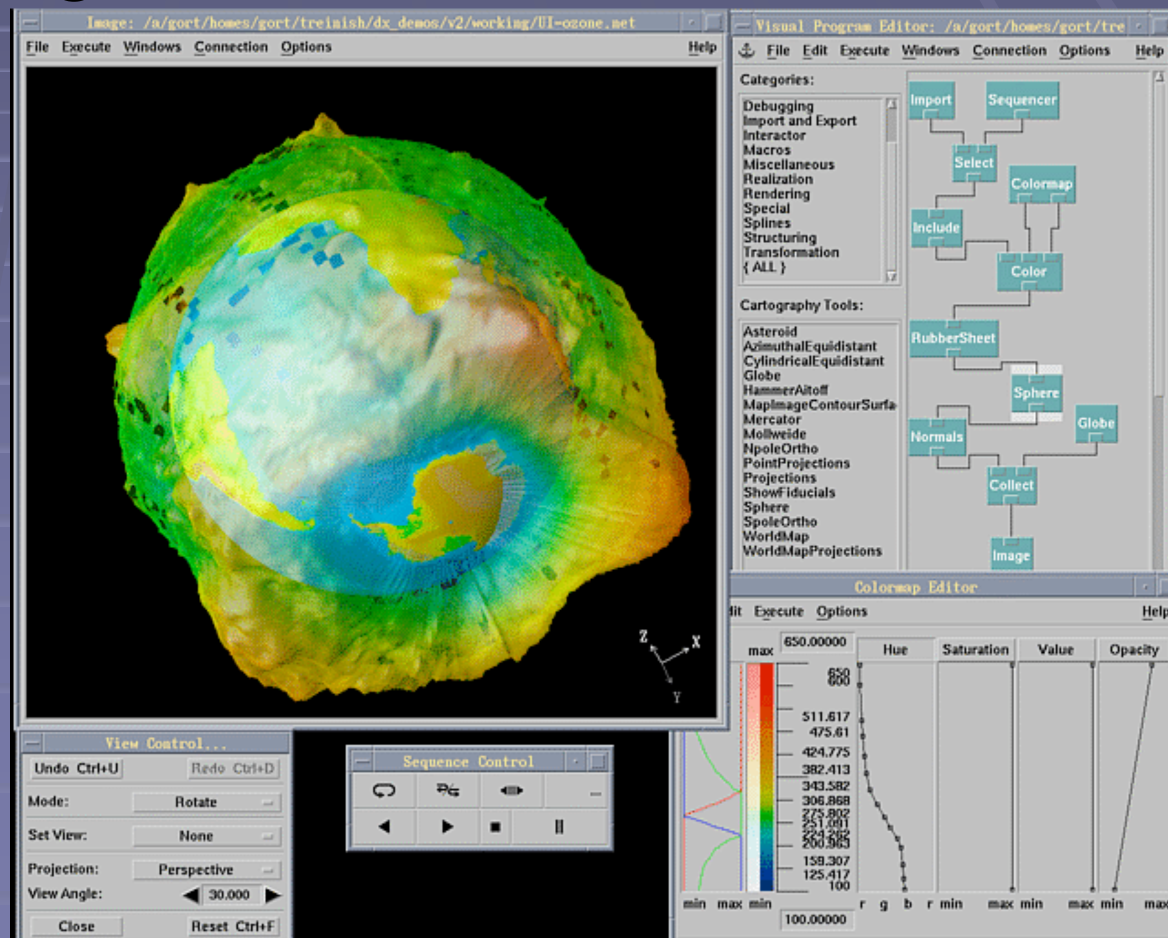
- IBM Open Visualization Data Explorer
  - Portable, general purpose software package for data analysis and visualization.
  - Introduced by IBM in 1991 Used in.
    - Academics, Industry, and governments worldwide
    - Uses graphics from OpenGL
  - Supports multi-processor, parallel workstations and servers.

OpenDX Cont.

- GUI is built on standard interface
  - OSF/Motif™
  - X Windows Systems™
- Has Variety of interactors
  - Direct – rotate or zoom
  - Indirect – dials, switches, buttons, sliders
- Designed for Client/Server environment.

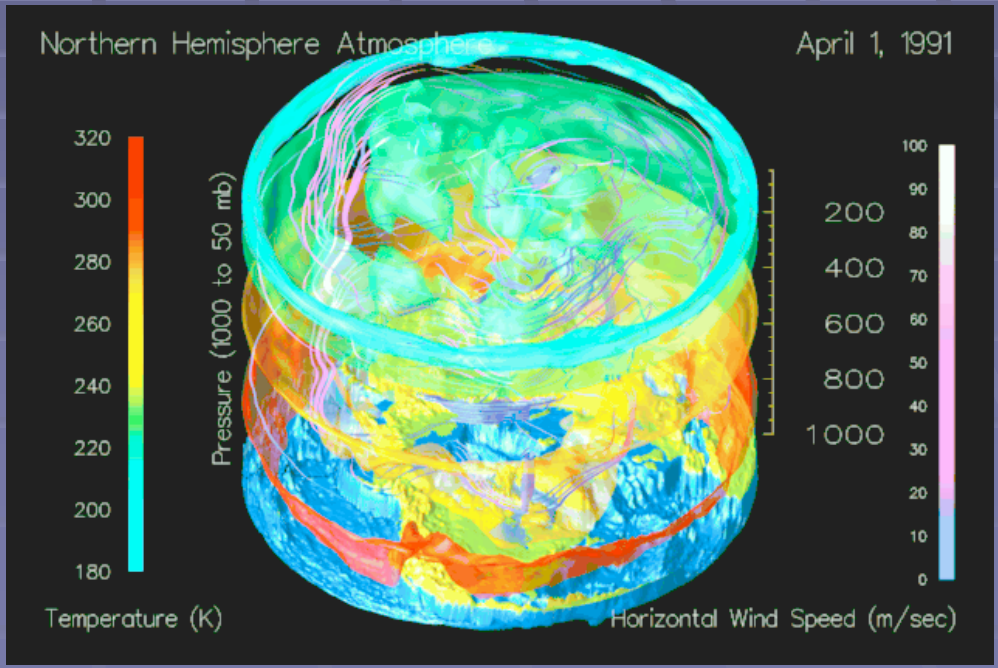
OpenDX Example Meteorology

- Current Ozone global view
  - 366-frame Animation
  - Data from Nimbus-7 Spacecraft



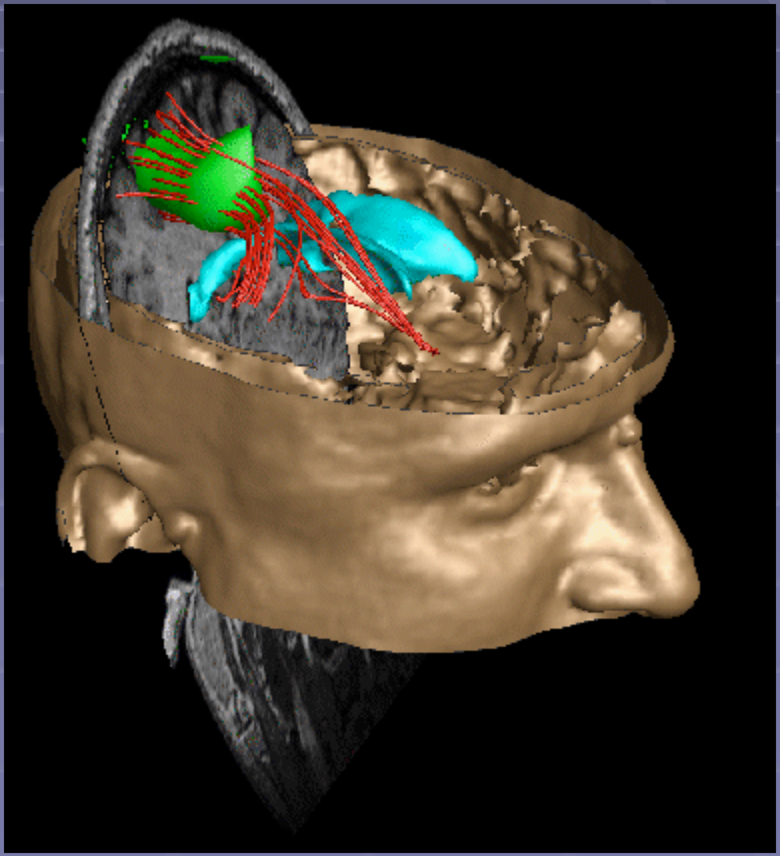
OpenDX Example Meteorology

- North Hemisphere Atmosphere
  - Temperature data are shown colored translucent isosurfaces.
  - Winds shown colored streams
  - Pressure cylines
  - Base topographic map.



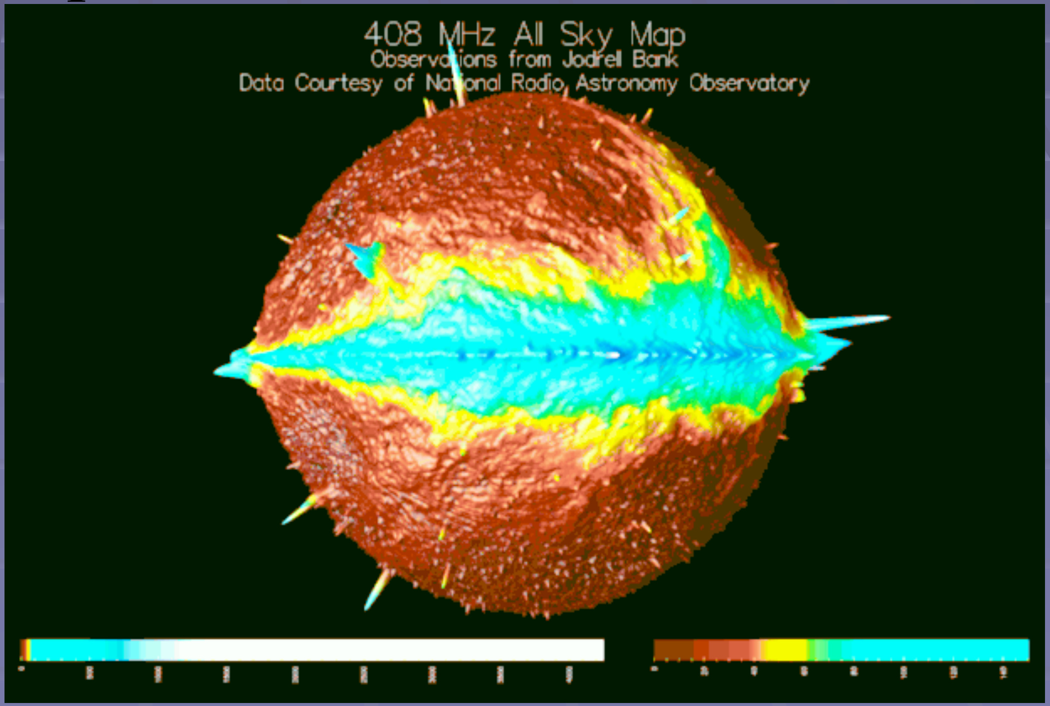
OpenDx Examples Medicine

- 3D MRI & Magnetoencephalopgraphic scan
  - Display of Skin
  - Lateral Ventricles
  - Shows MRI 2D image
  - High density (green)
  - Current flux lines (red)



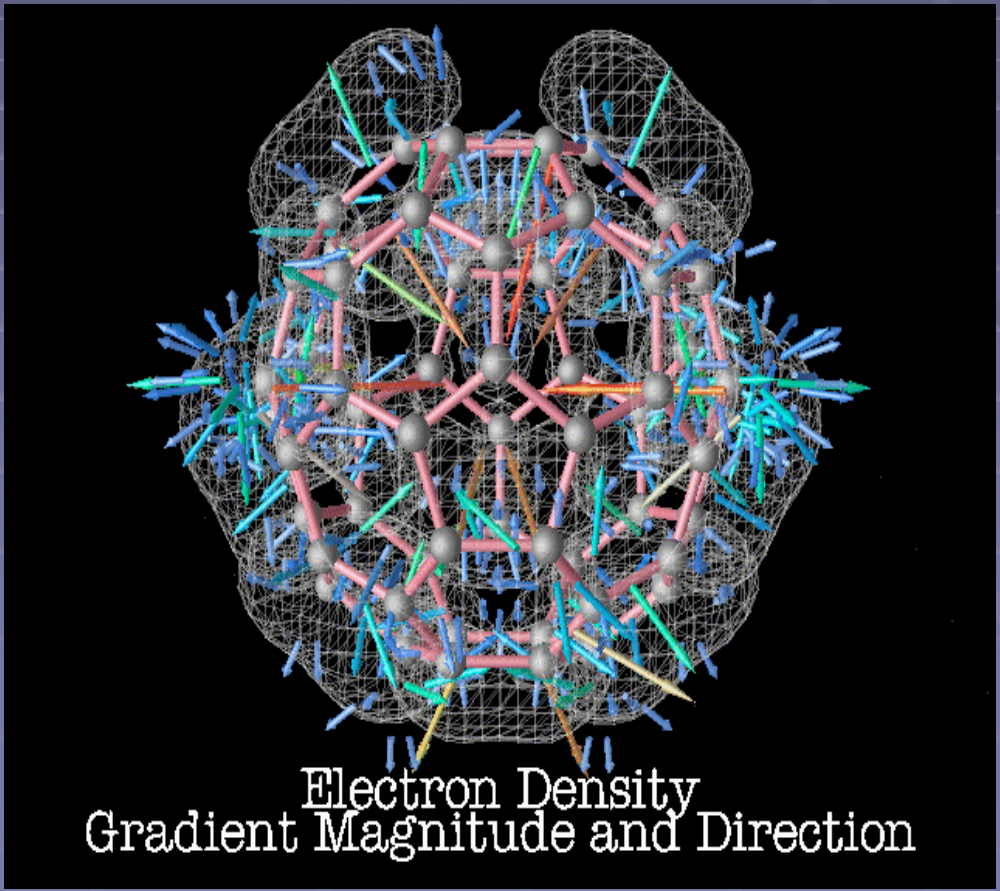
OpenDX Space Sciences

- The Radio Sky
  - Observations in galactic coordinates
  - Radially deformed sphere
  - Intense band equator
    - Milky Way



OpenDX Example Chemistry

- Electron density C60 Bucky Ball
  - Dot Surface
    - Highest occupied orbitals
  - Colored Arrows
    - Magnitude
    - Direction



Overview of Software

- NCL
  - Easy to use, Fast configureation
  - Small projects
  - Light Graphics, best if 2D
- Amira
  - Harder to use, Longer setups
  - Large to Huge projects
  - High performance Graphics
  - Can us 1D 2D 3D effectively.

Overview of Software

- OpenDX
  - Longer setups, Hardest to use
  - Large to massive sized projects
  - Highest performance graphics
  - Can be used in more fields then Amira
  - Has 1-3D graphics uses them flawlessly.
  - Is Free, Open source.

References

http://www.nat.vu.nl/~pwgroen/vis/soft/dx/dx.html

http://www.nas.nasa.gov/Groups/VisTech/visWeblets.html

http://www.vets.ucar.edu/software/index.shtml

http://www.tgs.com/index.htm?pro_div/amira_main.htm~main

Present and future challenges

A brief overview of the paper

"Visual Supercomputing. Technologies, Applications and Challenges",
presented at the Annual Conference of the European Association for Computer Graphics

EUROGRAPHICS 2004

08/31/04 – 09/03/04

Grenoble (France)

Elissaveta Arnaoudova

Introduction

Today's reality - a variety of computational resources available to visualization:

- visualization capabilities provided through modern desktop computers and powerful 3D graphics accelerators
- high performance computing facilities to visualize very large data sets or to achieve real-time performance in rendering a complex visualization
- visualization capabilities, provided through mobile computing systems, such as PDAs

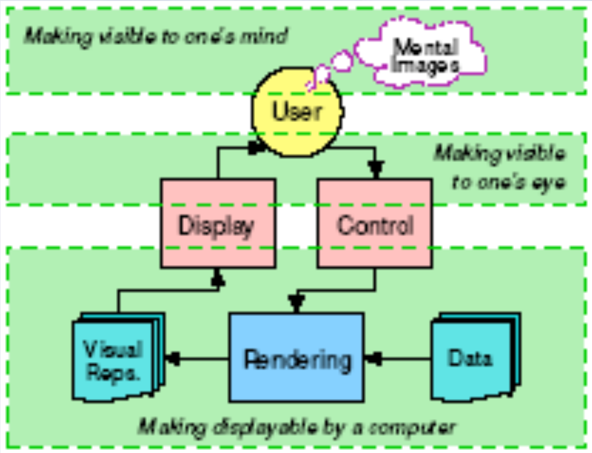
- **Significant growth in:**
  - size of visualization data (e.g., in visual data mining)
  - complexity of visualization algorithms (e.g., with volumetric scene graphs)
  - demand for instant availability of visualization (e.g., for virtual environments)

The concept of Visual Supercomputing

- ***What is it?***

- **It is concerned with the infrastructural technology for supporting visual and interactive computing in complex networked computing environments.**
  - encompasses a large collection of hardware technologies and software systems for supporting the computation and management of visualization tasks
  - addresses issues such as the scheduling of visualization tasks, hardware and software configurations, parallel and distributed computation, data distribution, communications between different visualization tasks
  - provides infrastructural support to users' interaction with visualization systems

Semantic Contexts



Level 1 - computational process of rendering a visual representation of the information.

A visual supercomputing infrastructure should address issues such as allocating and scheduling computational resources for visualization tasks, managing data distribution.

Level 2 - designing appropriate visual representations and conveying visual representations to viewers.

A visual supercomputing infrastructure should address issues related to the interaction between users and their visualization tasks, which can be conducted in a variety of forms, including interactive virtual environments, Internet-based collaborative environments, mobile visualization environments.

Requirements

Application Perspective

Increasing number of new applications results in new, and sometimes ***conflicting***, requirements:

- continuously growing size of datasets to be processed (e.g., bioinformatics) **vs.** necessity of a careful control of data size (e.g., mobile visualization).
- demand for a photorealistic visualization at an interactive speed (e.g., 3D virtual environments) **vs.** requirements for schematic visual representations and non-photo-realistically rendered images (e.g., visual data mining).
- achieving an interactive visualization with modern personal computers (e.g., virtual endoscopy) **vs.** demand for a more complex computational model (e.g., with distributed data sources or dynamic data sources).

So, a visual supercomputing infrastructure should provide a large collection of platforms, methods, mechanisms and tools to serve different applications

Requirements

User Perspective

- **Secretary-like visualization service**
  - requirements for the service to be tailored to individual needs. Visualization users are no longer limited to scientists and engineers and less technically oriented users would require a secretary-like visualization service, where they simply submit the data, give instructions and receive results.
- The emergence of ***autonomic computing*** in developing self-managed services in a complex infrastructure. Therefore a visual supercomputing infrastructure should have the responsibility for managing:

  • visualization resources,

  • visualization processes,

  • source data and resultant data,

  • users' interaction and communication, users' experience in accomplishing a visualization tasks.

Making Visual Supercomputing possible

Advances in technology contributing to visual supercomputing

- ***The Era of Supercomputers*** - Elwald and Mass's vector graphics library for Cray1 represents the earliest efforts for providing visualization capability to support scientific computation on supercomputers.
  - **Models of Parallel Computation**
    - ***Functional parallelism*** - achieved when different parts of data are processed concurrently by different functional sections on different processors.
    - ***Data parallelism*** - achieved when multiple streams of the data are computed in parallel.
    - ***Farm parallelism*** - splits up the process of computation into "tasks", each of which is a portion of data coupled with a functional operation to be performed.

Advances in technology (cont.)

- **Parallel Programming Paradigms**
  - message passing – “manually” specifying subtasks to be executed in parallel, start and stop their execution, and coordinate their interaction and synchronization.
    - Message Passing Interface (MPI) is one of the most popular programming environments for developing parallel applications in C/C++ and Fortran.
    - The Parallel Virtual Machine (PVM), first developed at Oak Ridge National Laboratory (ORNL) - enables programmers to treat a set of heterogeneous computers as a single parallel computer using the notion of a virtual machine.
  - shared-address-space - provides programmers with a virtual shared memory machine, which can be built upon distributed as well as shared memory architectures.
  - data parallel - provides programmers a collection of virtual processors.

Advances in technology (cont.)

- ***Graphics Workstations and Modular Visualization Environments***
  - replaced graphics as a specialty, provided in the form of a graphics terminal connected over a relatively slow communication line to a time-sharing processor. Suddenly the processor was co-located with the display, and so interaction became much more dynamic.

From Special Purpose Hardware to General Purpose Hardware

• Video random-access memory (VRAM)
• Graphics processors
• Multi-processor graphics architectures
• Texture mapping hardware - provided computer graphics and visualization with low cost pseudo photorealism.

Virtual Reality **-** immersive and semi-immersive

Fig. Semi-immersive VR

Advances in technology (cont.)

- ***The World Wide Web***
  - provides a generic framework, under which it is possible to deliver visualization services to every corner of the globe.
  - facilitates C**ollaborative Visualization** where geographically distributed users can work together as a team:
    - display sharing - a single application runs, but the interface is shared;
    - data sharing - data is distributed to a group of users to visualize as they wish;
    - full collaboration - the participants are able to program the way they collaborate.

Advances in technology (cont.)

- ***Grid Computing and Autonomic Computing***
  - The Grid - a distributed computing infrastructure for “coordinated resource sharing”.
  - Autonomic Computing - computing systems which possess the capability of self-knowing and self management. Such a system may feature one or more of the following attributes:
    - Self-configuring (integrate new and existing components)
    - Self-optimizing (determine the optimal configuration)
    - Self-healing (detect, and recover from, failure of components)
    - Self-protecting (detect attempts to compromise it)

Applications of Visual Supercomputing

Visual Data Mining and Large-scale Data Visualization

- Data repositories at terabyte level are becoming a common place in many applications, including bioinformatics, medicine, remote sensing and nanotechnology. Many visualization tasks are evolving into visual data mining processes. These applications demand a variety of infrastructural supports, such as:
  - providing sufficient run-time storage space to active visualization tasks;
  - managing complex data distribution mechanisms for parallel and distributed processing;
  - choosing the most efficient algorithm according to the size of the problem;
  - facilitating the search through a huge parameter space for the most effective visual representation.

Scientific Computation and Computational Steering

- ***Post-processing -*** visualization is a post processing stage of simulation. Simulation completes before visualization begins, so it cannot be directly influenced through the visualization.
- ***Tracking -*** the simulation and visualization are coupled, but the user cannot influence the simulation on the basis of the visualization, other than aborting it!
- ***Steering -*** the control parameters of the simulation are exposed, and can be manipulated as it runs.

Related software:

- **SCIRun** is a dataflow environment specially designed for steering. It facilitates the interactive construction, debugging and steering of large-scale scientific computations
- **CUMULVS** (Collaborative User Migration, User Library for Visualization and Steering) is a software framework for linking steering and visualization services with parallel simulation
- **RealityGrid** project used for demonstrations of steering massive Grid applications, involving collections of machines across the world and are state of art in what can be achieved on a global scale

Mission Critical Visualization

- Requires the real time processing of large datasets, possibly from diverse sources, that can then be fed into an interactive visualization environment.
- Application areas - defense and intelligence, law enforcement, healthcare and social services, scientific research and education, transportation and communication, energy and the environment.
- Medical simulators are a major application to benefit from simulator technology.

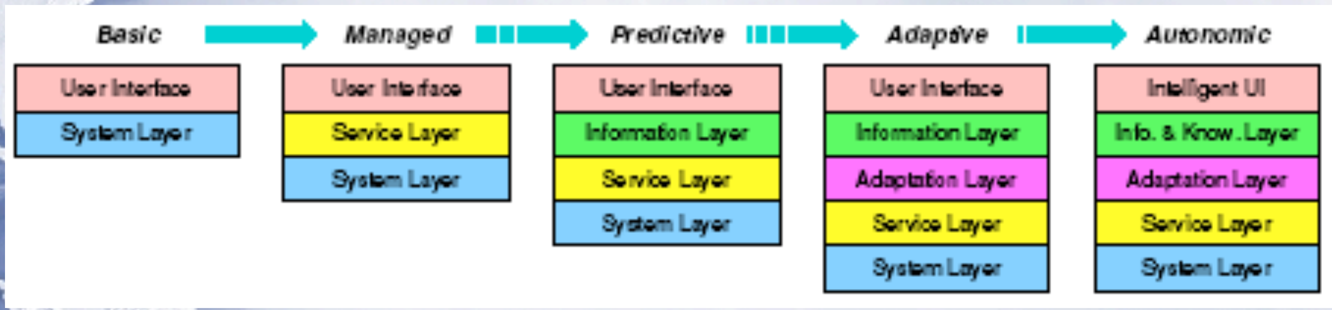
- For example, as shown in the figure, visualization tasks can be carried out on a server over a mile away from the hospital and then delivered across the data network. Applications such as this raise many issues including:
  - use of redundancy to ensure a reliable delivery of visualization;
  - handling of secure information, etc.

Mobile Visualization

- The prospect for integrating mobile devices into the visualization pipeline and its applications offers new opportunities for accessing and manipulating data remotely.

  - ***Demands:***
  - ***Remote monitoring*** — Users may query their account to retrieve images visualizing their data.
  - ***Remote steering*** — A remote user can be notified on job completion, and may view a visualization of the result. Limited interaction with the visual representation is possible as the user's feedback can be used to generate modifications to the current job.
  - ***Remote visualization*** — The user interacts freely with the simulation, using the visualization to explore all aspects of their data.

An envisioned model of the Visual Supercomputing infrastructure



The five-level deployment model for visual supercomputing, which can be developed evolutionarily:

- *Level 1:* ***Basic*** — Users are fully involved in finding appropriate tools, locating computation resources and dealing with networking, security, parallel computing, data replication, etc.
- *Level 2:* ***Managed*** — Introduction of a service layer between the user interface and the system platform which is aware of the availability of data and resources and can provide services to various visualization applications according to dynamic requirements of users and applications.

An envisioned model of the Visual Supercomputing infrastructure

- *Level 3:* ***Predictive*** — Information layer between the user interface and the service layer, which collects, monitors and correlates various user interaction data and system performance data. It provides users with analytical data, such as effectiveness of visualization tools as well as recommendations for suitable tools and visual representations.
- *Level 4:* ***Adaptive*** — A visual supercomputing infrastructure will have an adaptation layer between the information layer and the service layer. Based on the information collected, the adaptation layer has the functionality for self-configuring and self-optimizing the computational requirements of a visualization task, as well as the functionality for self-managing the system platform and various visualization services dynamically.
- *Level 5:* ***Autonomic*** — At this level, the traditional user interface in a visual supercomputing infrastructure will be replaced by an ***intelligent user interface***, for instance "a virtual secretary", which is capable of transforming information to knowledge and provides users with a wide range assistance, such as scheduling inter-dependent jobs, organizing raw data and visualization results, managing security, arranging the sharing of the data with other users, etc.

References:

- **http://eg04.inrialpes.fr/index.en.html**