Critical Needs from the Future Computer Environment

- Assistance in problem formulation
  - easy specification of 3D domains and constraints
  - easy application of governing equations to the domain.
    (some semi-automatic generation of computer codes)
- Assistance in solution analysis and understanding
- Assistance in communication of understanding (technology transfer)
Features Needed to Attain this Environment

- Computer interface that is a better match to the human cognitive capabilities
- Effective 3D object manipulation, sculpting, and viewing tools (3D interactive computer graphics)
- "common look and feel" for 3D manipulation, sculpting, and viewing (3D interactive graphics integrated into the operating system)
- Fast 3D rendering
- Tools for communications of ideas and concepts
  - tools for computer assisted presentations
  - tools to create "dynamic" publications

Prospects for Changes in the Human-Computer Interface

- recent changes
- restrictions still remaining
- projected future changes
- impact of these future changes
Revolution in the Human-Computer Interface

Prior to 1980 - primarily text input and output
1981 - introduction of the IBM PC
1982 - founding of Sun
by 1990 - interactive visual analysis
1 million pixels
16 million colors
mouse and keyboard controls

Restrictions Still Remaining in the Typical Human-Computer Interface Today
no stereo vision
uses only 1/25th of the field of view
no audio
primitive controls

Val Watson

NASA Ames Research Center
Nov 8, 1994
During the next 10 years, we will see a greater change in the bandwidth between the human and the computer than has occurred in all previous time or will occur in all time following.
Future Extension of Environment with Computers
(computer nearly fills the personal environment)

References on the Importance of Visualization

- The second computer revolution
  Richard Friedhoff and William Benzon
  Abrams Publishers

- Visualization in Visual Thinking
  Robert H. M. Kim
  PWS Publishers
The Need for More "Visual Thinking".

from "Experiences in Visual Thinking"

Robert McKim (Stanford University)

Schools emphasize and reward "symbolic thinking".

( inadvertently suppressing "visual thinking").

"Visual thinking" is better for many problems.

Therefore, we should recognize the value of "visual thinking".

- sharpen our "visual thinking" skills.
Example - "The Game" without visualization

There are 2 players.
Players alternately select numbers from the set of numbers 1 through 9.
Any number may be selected only once (if a number is selected, it is not available to the other player).
The object of the game is to be the first to select the numbers such that three of them add to 15.
Part of the game strategy is to pick numbers to prevent the opponent from getting 3 numbers that total 15.

Example - "The Game" with some visualization

1 2 3 4 5 6 7 8 9

2 players take turns taking disks from the row of disks above.
The object of the game is to be the first to select the disks such that three of them have numbers that add to 15.
Part of the game strategy is to pick disks to prevent the opponent from getting 3 that total 15.
**Example - "The Game" with more visualization**

Arranging the numbers spatially converts the game to Tic-Tac-Toe

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**Examples of the Importance of 3D**

**Reference**

*Perceiving Shape from Shading*

V. S. Ramachandran

*Scientific American, August, 1988*
Evaluation of the Alternate Approaches for Interactive Computer Graphics

- trade-offs in visualization
- distribution of tasks
- commercial packages vs in-house programs
- selection of tools for in-house programming

Trade-offs in Visualization

- Realism of scenes vs speed of interaction
- Support for general problems vs specific problems
- Portable code vs maximum performance code
Levels of Computer Graphics

- Low Level
  - points and lines
- Medium Level - important for understanding
  - solids (polygons)
  - hidden surface removal
  - smooth shading
  - approximate lighting and transparency
- High Level - used for realistic looking scenes
  - true lighting, shadows, and transparency (ray tracing)
  - correct color of reflected light (radiosity)

Important Techniques for Understanding Computational Fluid Dynamics

- Interactive viewing
  - interactive change of viewing position
  - interactive selection of properties-viewed
- Dynamic motion
- Multiple representations of the same data
- Feature highlighting techniques
- Comparison techniques
Requirements for Rendering the Representations

- All current popular scenes can be created with
  - 3D surfaces
  - 3D lines
  - points
- Surfaces are composed of 4 sided non-planar polygons
  (flat shading is sometimes preferred)
- Typical scenes use of the order of 10,000 polygons
- 10 "frames/sec" are needed to understand dynamics

Therefore, the derived requirement is
100,000 polygons/sec with hidden surfaces removed

Visual Analysis for Computational Fluid Dynamics

the purpose is

UNDERSTANDING

not

ART OR REALISM

Speed is more important than true lighting for understanding dynamical interactions
NASA Decisions on Visualization for Computational Fluid Dynamics

- High performance on the medium level graphics over slower performance on high level graphics
- High performance specifically for computational fluid dynamics problems over generality
- High performance on specific platforms over portability of code

Distribution of Tasks?

Remote Facility | Scientist's Office
-----------------|-------------------
? ← Simulation → ?
? ← Scene Creation → ?
? ← Scene Viewing Orientation → ?
? ← Projection to 2D → ?
? ← Rendering to Pixels → ?
All of the Work Done on a Remote Facility

Remote Facility  Scientist's Office

Simulation
Scene creation
Scene viewing orientation
Projection to 2D
Rendering to pixels

Most of the Work Done on a Remote Facility

Remote Facility  Scientist's Office

Simulation
Scene creation
Scene viewing orientation
Projection to 2D
Rendering to pixels

X Window Server

Notes

Visual Environments for CFD Research  Val Watson  NASA Ames Research Center  Nov 8, 1994
Most of the Graphics Done on a Workstation

Remote Facility  Scientist's Office

Simulation
Scene creation

3D Workstation

Scene viewing orientation
Projection to 2D
Rendering to pixels

All of the Graphics Done on a Workstation

Remote Facility  Scientist's Office

Simulation

3D Workstation

Scene creation
Scene viewing orientation
Projection to 2D
Rendering to pixels

Notes
Guidelines

(usually valid)

Computer performance/price inversely related to size (Grosch's law is no longer valid)

Custom chips improve performance/price for specific tasks

For fluid dynamics research, the volume of data usually increases with each phase of the analysis and scientists are more productive in their offices and are less inclined to use equipment distant from their offices.

Trends impacting the Environment of the Future

- Large computers - general tasks
- Small computers - specialized tasks

Cost per task

Time
Calculation of Data Volumes
Data from simulation
1 million grid points for computation
x, y, z location for each computational grid point
with 4 bytes for each value = 12 bytes/point
5 primary variables at each grid point
with 4 bytes for each value = 20 bytes/point
Total ~ 30 MBytes
Data for 5 minutes of dynamic viewing
24 bits of color information = 3 bytes/pixel
1280 X 1024 = 1.3 million pixels per frame
15 frames per second = 4,500 frames for 5 minutes
Total ~ 20 GBytes

Distribution of Tasks Selected for the NASA Facility
• The simulation is performed on the supercomputer
  because of memory requirements
• A substantial investment is placed in graphics to provide
  for the maximum effectiveness of the total system
• The graphics displays are placed in the scientist's office to
  maximize the productivity of the scientist
• Most of the graphics work is done on the workstation
  because it is more cost effective than doing it on the
  supercomputer
**Distribution of Computing Power**

- **Workstations**
- **Supercomputers**

**Workstation Features**
(Silicon Graphics Power Indigo2)

**Basic Workstation Features**
- Linpack 1000x1000: 230 MFLOPS
- Primary memory: 384 Mbytes

**Graphics Features**
- Solids rendering: 155K indep. quads/sec
- (~10,000 indep. quads at 15 frames/sec)
Performance Measures for Workstations

- SPEC (System Performance Evaluation Cooperative)
  - Performance for a series of "typical" scientific tasks except for graphics
- GPC (Graphics Performance Characterization)
  - Performance for 2D and 3D graphics

For more information on SPEC

Joan Martinez
Systems Performance Evaluation Cooperative
39510 Paseo Padre Parkway, Suite 350
Fremont, California 94538
Telephone - (408) 433-5220
FAX - (408) 433-8723
GPC Benchmarks
1. pc_board
   2D markers, lines, and text performance
2. sys_chasis
   wireframe mechanical CAD performance
3. cyl_head
   solids mechanical CAD performance
4. shuttle
   low end simulation performance
5. head
   animation & visualization performance

The Performance Measure for Visualization
GPC benchmark for "head"
- Approx. 60,000 triangles representing a human head
- Gouraud shading, 4 light sources
- Animation is 3 rotations in 240 frames

A GPCmark of 1 is approx. 3K triangles/sec
Recommend a minimum of 30 GPCmarks for visualization

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For more information on GPC

Dianne Dean
NCGA (National Computer Graphics Assn.)
2722 Merrilee Drive, Suite 200
Fairfax, VA 22031
Telephone - (703) 698-9600 ext 318
FAX - (703) 560-2752

In-House Programming vs. Available Packages

- time required
- support available
- flexibility

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Visualization Software from Vendors (part 1)
(partial list)

- AVS - Stardent
- Data Explorer - IBM
- Data Visualizer - Wavefront
- Explorer - Silicon Graphics
- Field View - Intelligent Light
- Flow Eyes - SOLIDRAY Co., LTD
- FOCUS - Visual Kinematics
- IDL - Research Systems Inc.
- IVM - Dynamic Graphics, Inc.

Visualization Software from Vendors (part 2)
(partial list)

- MPGS - Cray
- OMNIS3D - Analytical Methods, Inc.
- PV Wave - Precision Visuals
- Spyglass - Spyglass Inc.
- SSV - Sterling Software
- SUN View - SUN Microsystems
- TECPLT - Amtec Engineering Inc.
- VIX PLOT3D - Visual Computing Inc.
- Voxel View - Vital Images
### Early Visualization Software from Ames
(Transferred to COSMIC for Distribution)

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### New Visualization Software
(partial list)
- **Government**
  - FAST - NASA Ames (Sterling Soft.)
  - Rambo - Air Force (Aerospace Corp)
- **Universities**
  - apE - Ohio Supercomputer Center
  - Visual3 - MIT
- **Vendors**
  - many - shown on following slides

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Visual Environments for CFD Research  Val Watson  NASA Ames Research Center  Nov 8, 1994
Some Visual Techniques Provided

- Particle traces
- Showing scalar values on surfaces as color (function mapped surfaces)
- Isosurface
- Arbitrary cutting planes
- Extraction and display of topology
- Transparency
- 2D plots of cross sections

Differences in Visualization Software

- Types of visual techniques supported
- Types of data structures supported
- Fraction of workstation performance achieved
- Number of workstations supported
- Portability to other workstations
Comments on the Data Flow Packages
(e.g. AVS, apE, Explorer, Data Explorer)

- Easy to learn and easy to use for small problems
- Excellent for prototyping
- Probably not as efficient for large problems

Tools for In-House Programming

- High Level, e.g. data flow programs
- Intermediate Level, e.g. Inventor from SGI
- Low Level, e.g. SGI's Open GL
Why not PEX?

- Some techniques require more access to the hardware than PEX allows.
  e.g., both Visual3 and FAST require reading from the Z Buffer.

Why not PHIGS?

- Fluid flow, turbulence... are all simulations that do not work well and are not well validated for display lists. The time and cost for rebuilding the display lists are too excessive.

Donald Greenberg, Cornell University
IEEE Computer Graphics and Applications
January, 1991
Recommendations for In-House Programming

- use data flow packages for small problems
- use data flow packages for prototyping
- use Inventor and Open GL for creating tailored programs for problems that require high performance

Probable Standards for Low Level Programming

- Windowing - X Windows
- Interface design - Motif
- 3D graphics - Silicon Graphics Open GL

Visual Environments for CFD Research       Val Watson       NASA Ames Research Center   Nov 8, 1994
Factors that Frequently Cause Problems

- Many (but not all) people use a screen coordinate system that is left handed
- Some use matrix notation opposite the standard of linear algebra texts
  - Foley and VanDam changed to the standard in their new book
- Some transformations are not commutative
  - the order of some transformations is important
- Rotation and scaling is about the coordinate system origin and not the center of the object

Some Deficiencies of Current Interactive Computer Graphics

- rendering speeds are sometimes too slow to permit understanding of dynamics or to facilitate easy manipulation
- magnitudes of inaccuracies due to rendering are usually not apparent
- approximation techniques are often not tuned to the nature of the data
- interfaces are usually not similar between applications
- the human-computer interface still has a bandwidth mismatch
- the human-computer interface is still not tuned to the human cognitive capabilities
Some Specific Techniques in Interactive Computer Graphics

- function maps (scalars shown as colors on surfaces)
- table lookup mode (no lighting permitted)
- rgb mode (lighting permitted)
- isosurface (surface with some value equal to a constant)
  - marching cube method
- arbitrary cutting plane or geometric shape
- marching cube (same as isosurface problem)
- particle traces
  - usually Runge Kutta instead of multiple steps to save storage

Some Specific Techniques in Interactive Computer Graphics - continued

- ribbon traces and "stream tubes"
  - MIT methods
- topology extraction
  - Find the points where the velocity is zero, calculate Jacobians at these points, and then create bounding lines or surfaces for the topological regions
- Stereo
  - should use true field of view (see additional notes)
- Zoom box in 3D scenes
  - should use translation rather than an artificial change in the field of view (requires reading Z buffer)
Research Aimed at Eliminating these Deficiencies

- Research at Stanford University on
  - increasing rendering speeds by using "sparse modes"
  - making magnitudes of inaccuracies visible
- Research by Butler on databases with approximation techniques associated with the data
- Research at NASA Ames on creating a single visual environment for computational fluid dynamics
- Research at many places on better human-computer interfaces
- Research on feature extraction and empirical human cognition matching

Current Flow Analysis Environment

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**Flow Analysis Software Toolkit (FAST)**

Environment

- Interface
- Grid Generation
- Flow Solving
- Visual Analysis
- Data

**Key Features of FAST**

- Highly interactive and visual interface
- Shared data - no multiple copies of data
- Multiple processes - only need memory for processes used
- Easy to add custom modules using "skeleton"
- Designed for distributed processing
Current Research on Human-Computer Interfaces

- "Virtual Environment" research
  (scientist feels like he is inside the simulated field)
  - Helmet display fills the field of view
  - Display corresponds to head position
  - Voice recognition
  - Data gloves for manipulation of objects
- Locations of VR research (partial list)
  - University of Washington - Tom Furness III
  - University of North Carolina - Henry Fuchs
  - Artificial Reality Corp. - Myron Kruger
  - NASA Ames - Ellis & McGreevy, Levit & Bryson

Current Research on Feature Extraction and Empirical Human Cognition Matching

- Stanford University - topology extraction
  - Hesselink and Helman
- University of Lowell - multi-variable icons
  - Grinstein
- NASA Ames Research Center - topology extraction
  - Kerlick and Globus
- NASA Ames Research Center - "boids"
  - Hultquist

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Recommendations

- Think 3D!! Take advantage of the human's 3D processing capabilities.
- When designing a computer system, distribute a significant fraction of the computer resources to the user's desktop.
- Specify a minimum interactive 3D graphics capability for the desktop workstation so everyone can communicate with each other effectively in 3D. (I recommend a minimum of 30 on the GPC "head" benchmark for new procurements)
- When designing in-house software, use a common "look and feel" for the interface. (SGI's Inventor may become commonly used)

Recommendations (continued)

- When designing in-house visualization software, use SGI's Open GL. (For CAD/CAM, PHIGS may be appropriate.)
- Associate the approximation techniques with the nature of the data rather than binding a single approximation technique with the visualization software.
- Provide a means to view the magnitudes of the inaccuracies of the approximations.
- Investigate and apply technologies for matching the scenes to the human cognitive capabilities.