Workshop
Improving the CFD Application Process
Stanford, University
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Visual Environments for CFD Research

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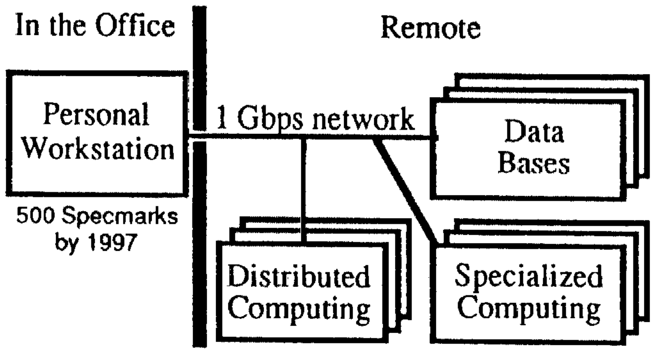
The Scientist's Environment of the Future



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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)

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Notes

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

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Prospects for Changes in the Human-Computer Interface

- recent changes
- restrictions still remaining
- projected future changes
- impact of these future changes

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Notes

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
- 19" screen
- 1 million pixels
- 16 million colors
- mouse and keyboard controls

--- *a major change in only 10 years*

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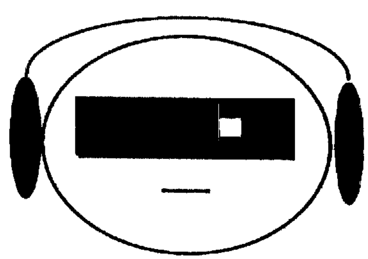
Restrictions Still Remaining in the Typical Human-Computer Interface Today



- no stereo vision
- uses only 1/25th of the field of view
- no audio
- primitive controls

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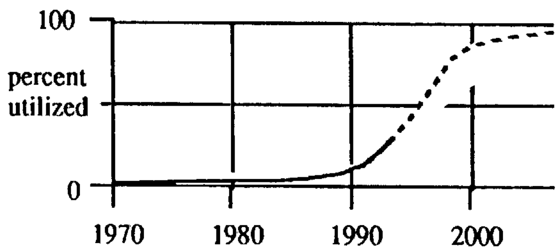
Notes

Fraction of Potential Bandwidth Utilized by the Human-Computer Interface



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

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Impact of the Revolution
In the Human-Computer Interface

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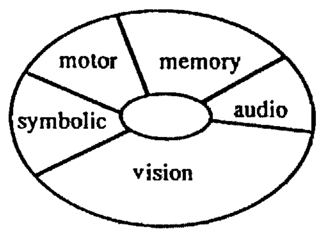
Notes

Human Processing Capabilities



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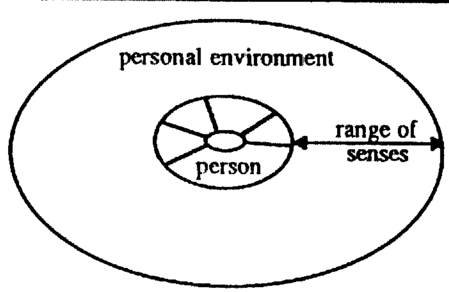
Limits of the Personal Environment



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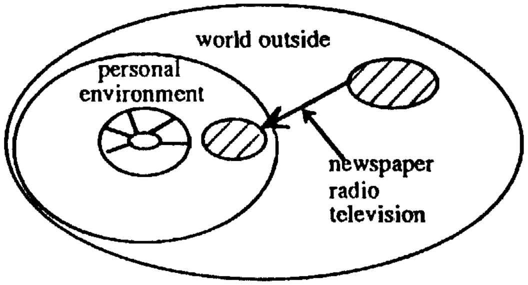
Notes

Extension of Environment with Technology



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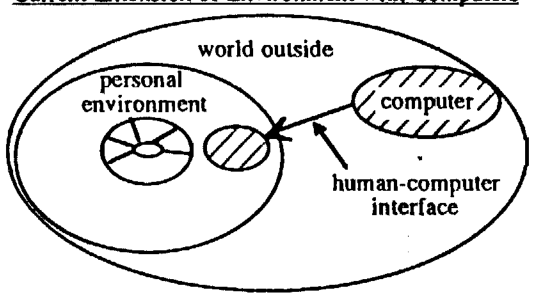
Current Extension of Environment with Computers



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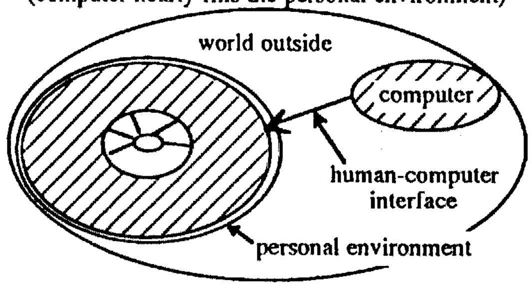
Notes

Future Extension of Environment with Computers
(computer nearly fills the personal environment)



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References on the Importance of Visualization

experiences in visual thinking
Robert H. McKim
PWS Publishers

Visualization - the second computer revolution
Richard Friedhoff and William Benzon
Abrams Publishers

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Notes

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

The human is highly suited to "visual thinking"

Therefore, we should
- recognize the value of "visual thinking"
- sharpen our "visual thinking" skills

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Illustrations of the Power of Visual Senses

- Face recognition from many angles
- Stereo composition
- Spatial positioning assisting in logic

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Notes

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.

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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.

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Notes

Example - "The Game" with more visualization

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

6	7	2
1	5	9
8	3	4

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Examples of the Importance of 3D

Reference

Perceiving Shape from Shading
V. S. Ramachandran
Scientific American, August, 1988

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Notes

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

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Trade-offs In Visualization

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

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Notes

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)

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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

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Notes

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

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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

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Notes

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

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Distribution of Tasks?

Remote Facility		Scientist's Office
? ←	Simulation	→ ?
? ←	Scene Creation	→ ?
? ←	Scene Viewing Orientation	→ ?
? ←	Projection to 2D	→ ?
? ←	Rendering to Pixels	→ ?

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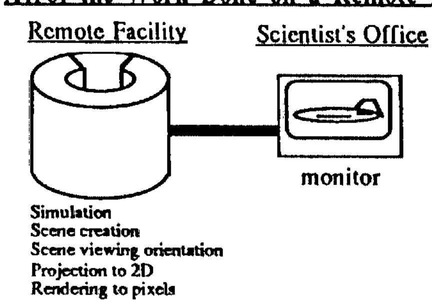
Notes

All of the Work Done on a Remote Facility



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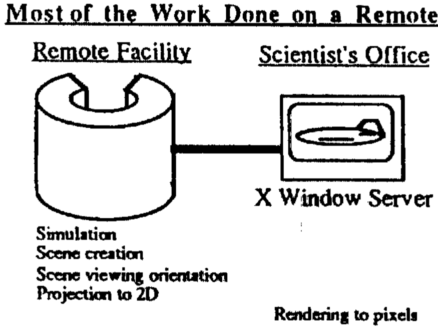
Most of the Work Done on a Remote Facility



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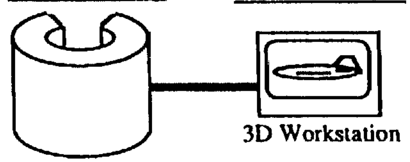
Notes

Most of the Graphics Done on a Workstation

Remote Facility — Scientist's Office



Simulation
Scene creation

Scene viewing orientation
Projection to 2D
Rendering to pixels

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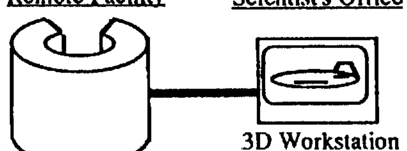
All of the Graphics Done on a Workstation

Remote Facility — Scientist's Office



Simulation

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

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Notes

Guidelines
(usually valid)

Computer performance/price inversely related to size (Groesch'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

Scientists are more productive in their offices and are reluctant to use equipment distant from their office

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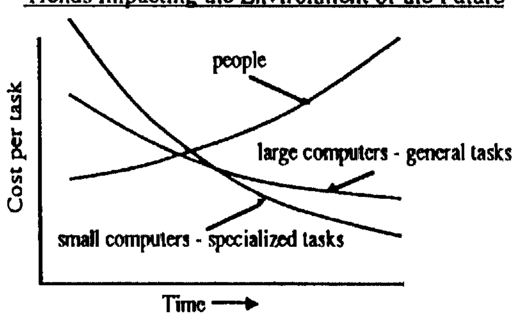
Trends Impacting the Environment of the Future



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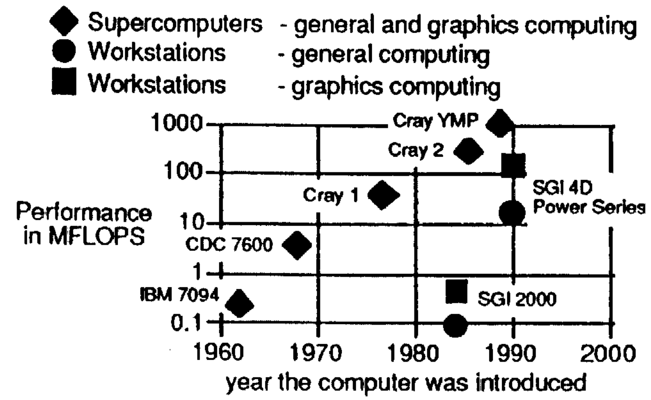
Notes

Performance Trends of Supercomputers and Workstations



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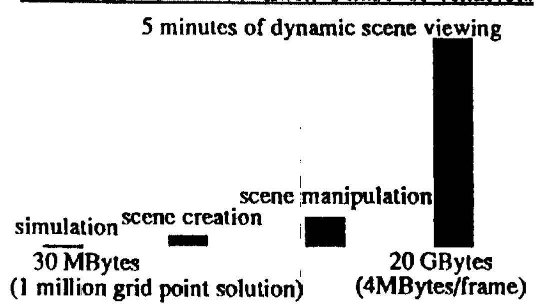
Volume of Data for Each Phase of Analysis



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Notes

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

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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

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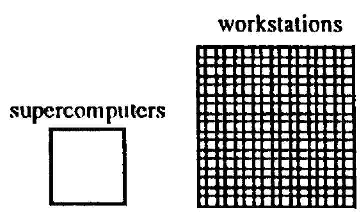
Notes

Distribution of Computing Power



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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)

Notes

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

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For more information on SPEC

Joan Martinez
Systems Performance Evaluation Cooperative
39510 Paseo Padre Parkway, Suite 350
Fremont, California 94538
Telephone - (408) 453-5220
FAX - (408) 453-8723

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Notes

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

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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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Notes

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

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In-House Programming vs Available Packages

- time required
- support available
- flexibility

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Notes

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.

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

MPGS	- Cray
OMNI3D	- Analytical Methods, Inc.
PV Wave	- Precision Visuals
Spyglass	- Spyglass Inc.
SSV	- Sterling Software
SUN View	- SUN Microsystems
TECPLOT	- Amtec Engineering Inc.
VCI PLOT3D	- Visual Computing Inc.
Voxel View	- Vital Images

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Notes

Early Visualization Software from Ames
(Transferred to COSMIC for Distribution)

Simulation	Visualization and Recording			
	Scene Creation	Scene Viewing	Animation Sequence Creation	Recording on Film and Video
	← PLOT3D →			
	← SURF →			
	← RIP →			
		← GAS		→

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

Notes

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

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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

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Notes

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

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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

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Notes

Why not PHIGS?

" --- fluid flow, turbulence ---- are all simulations that change with time, both geometrically and topologically, and thus are models not well suited 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

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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

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Notes

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

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Probable Standards for Low Level Programming

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

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Notes

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

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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

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Notes

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

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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)

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Notes

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 data bases with approximation techniques associated with the data
- Research at NASA Ames on creating a single visual environment for computational fluid dynamics
- Research many places on better human-computer interfaces
- Research on feature extraction and empirical human cognition matching

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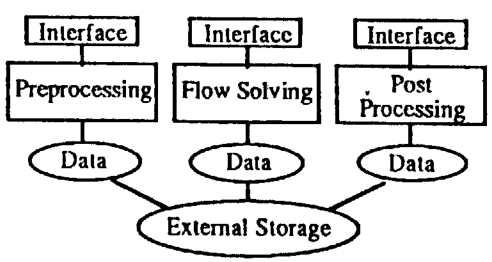
Current Flow Analysis Environment



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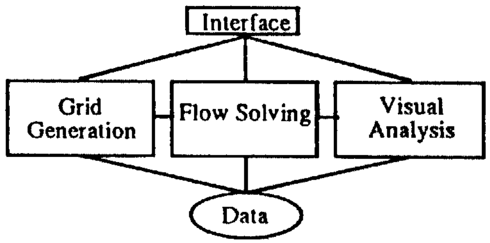
Notes

Flow Analysis Software Toolkit (FAST) Environment



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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

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Notes

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

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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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Notes

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)

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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.

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Notes