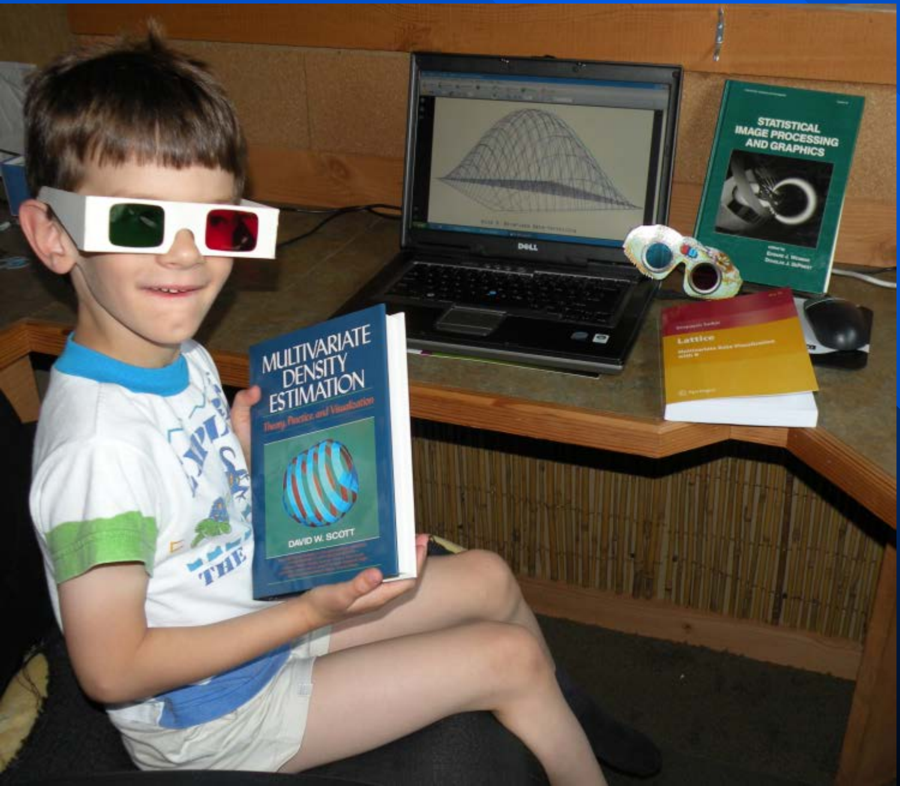
Stereoscopic Displays and Virtual Reality for Statistical Graphics

Jürgen Symanzik

Utah State University, Logan, UT, USA



e-mail: symanzik@math.usu.edu

http://www.math.usu.edu/~symanzik

HU Berlin, IRTG Short Course (I)

July 20, 2016

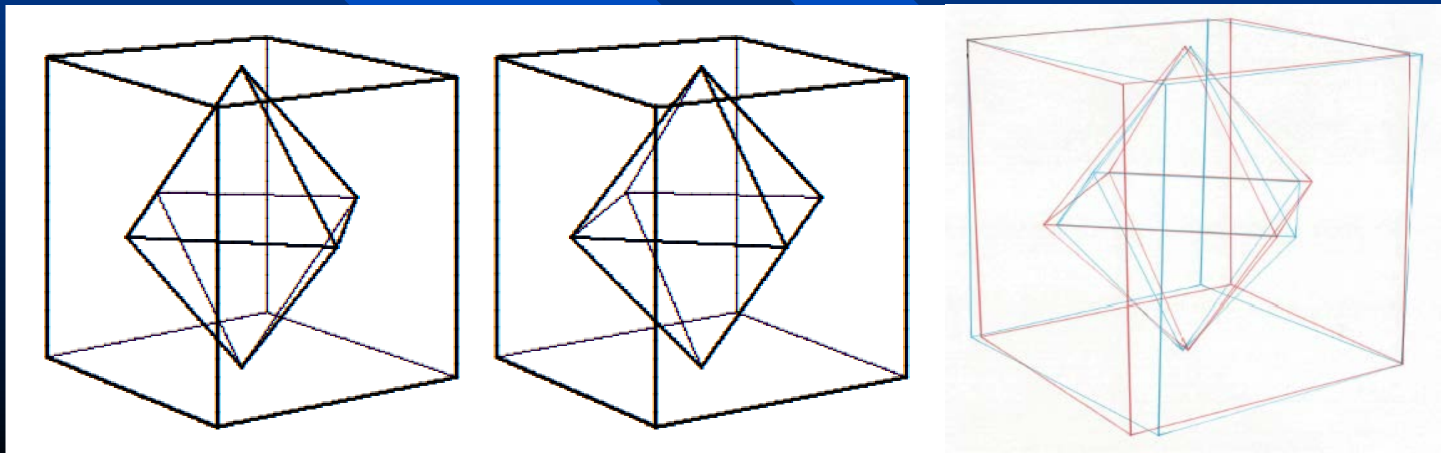
Outline

- Part I: 3-D Stereoscopic Plots – From History to R
- Part II: Statistics and Virtual Reality at Iowa State University (1995-1997)
- Part III: Statistics and Virtual Reality at George Mason University (1997-1999)

Part I: 3-D Stereoscopic Plots – From History to R

Contents

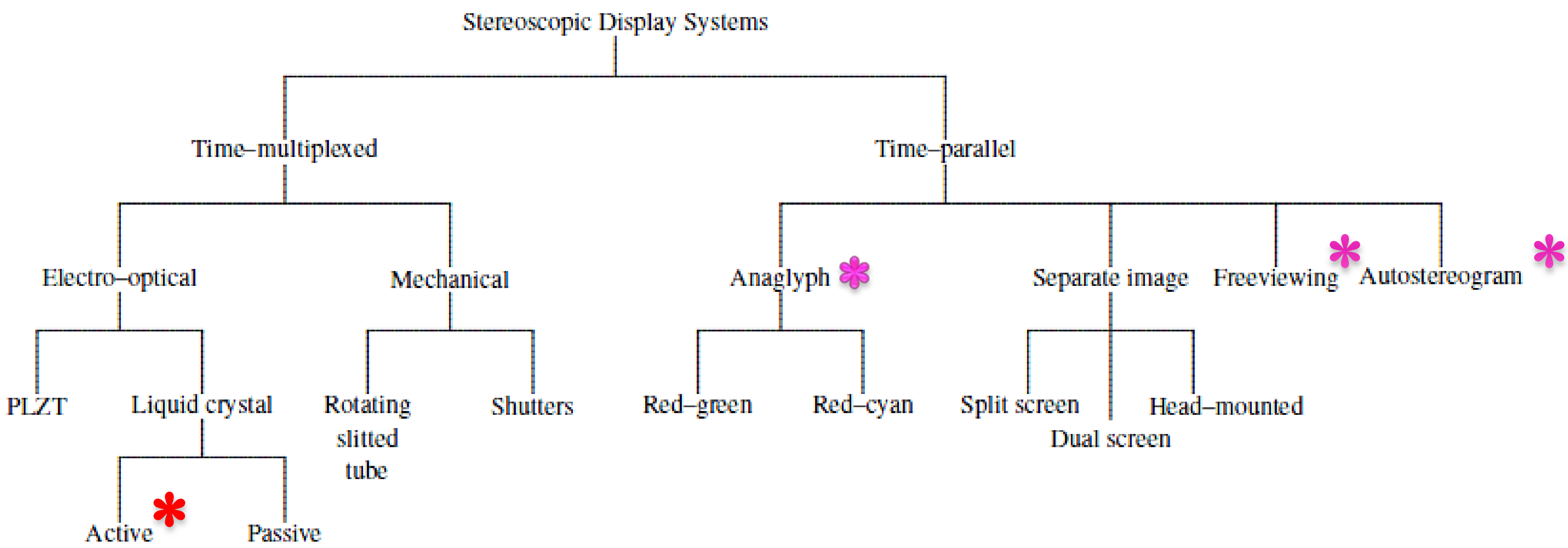
- Background on 3-D Stereoscopic Graphics
- History
- Mathematical Calculations
- Applications in Statistics: Then …
- Applications in Statistics: … & Now
- Outlook



Background

- 3-D Stereoscopic Graphics allow human viewers to interpret plots as realistic 3-D images
- Exists for paper, computer screen, or projections
- 3-D effect because each eye sees a slightly different image
- Human brain combines both images to 3-D image

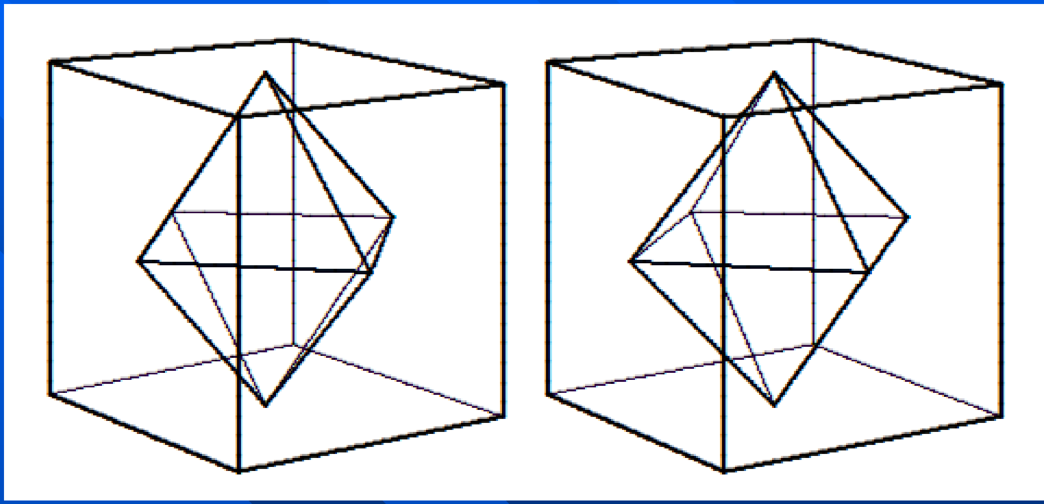
Types of Stereoscopic Displays



Adapted and extended from Hodges (1992); * discussed in Part I; * discussed in Parts II & III

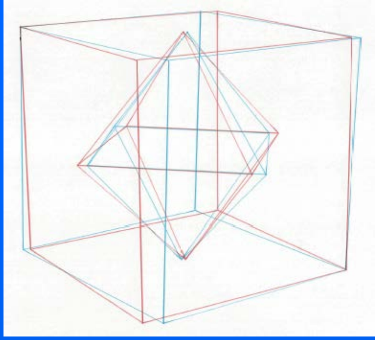
Freeviewing of Side-by-Side Images

- Viewer looks at 2 slightly different images, drawn side-by-side



- No tools needed
- Viewing techniques
  - – Focus on point before viewing plane
  - – Focus on point behind viewing plane
- One 3-D image & 2 ghost images

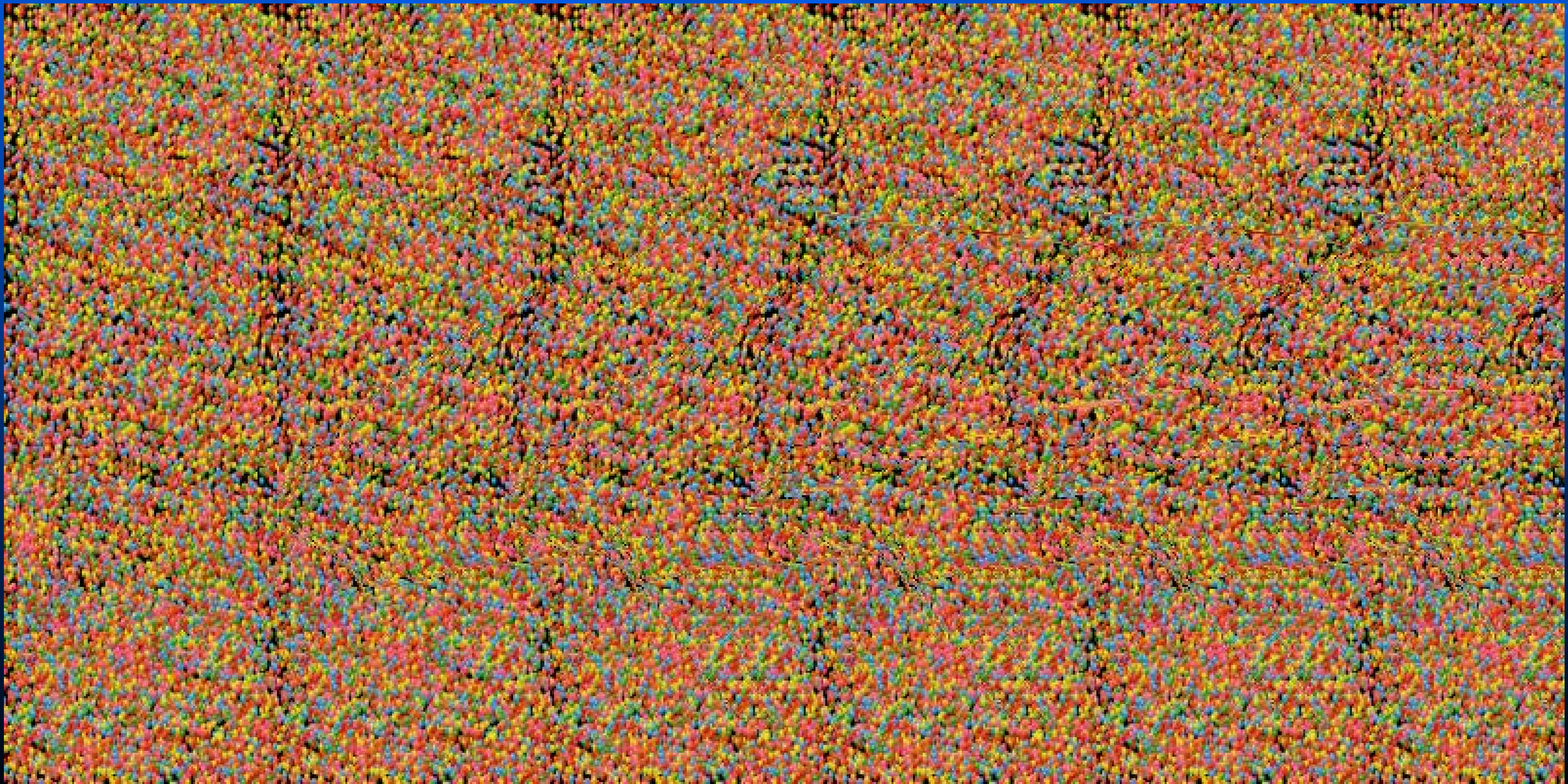
Anaglyphs



- Word “anaglyphos” originates from Greek
- Meaning: object is shaped relief–like, i.e., has a non–flat surface
- Two projections of a 3–D image looked at through filter glasses
- Common colors: red-green (print), red-cyan (CRT), also: red-blue & magenta-green
- Filter glasses filter out one of the images
- Brain combines different images into 3-D image

Autostereograms (1)

- Look like random noise or colorful patterns
- 3-D image revealed when looked at in a technique similar to the freeviewing of side-by-side images



Autostereograms (2)

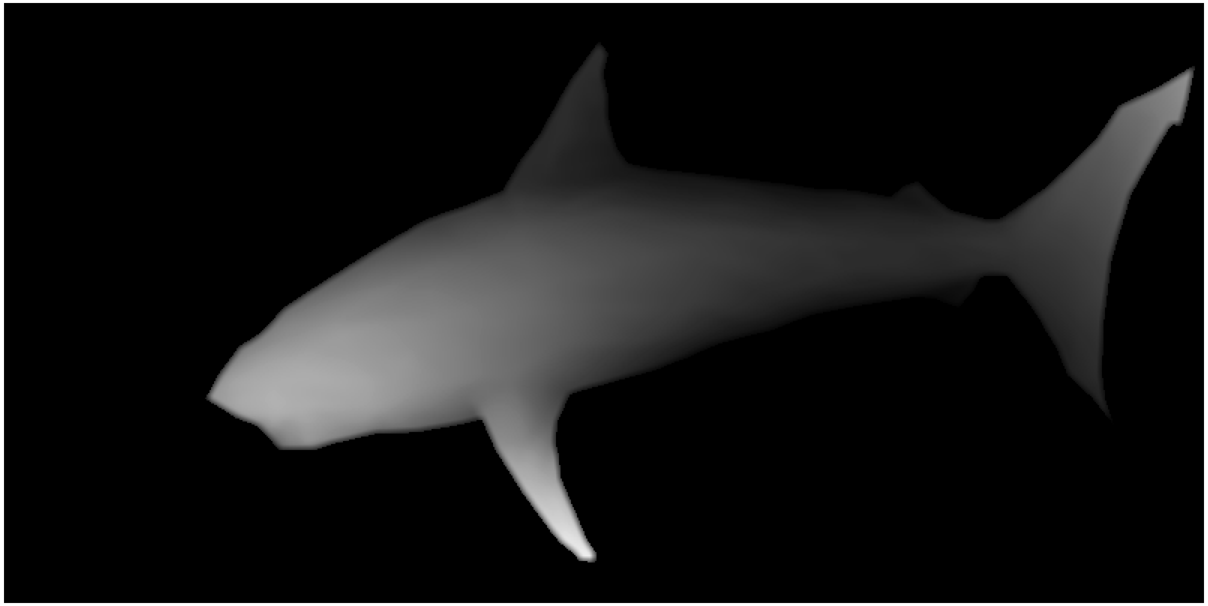
File:Stereogram Tut Random Dot Shark.png - Wikipedia, the free encyclopedia - Windows Internet Explorer

http://en.wikipedia.org/wiki/File:Stereogram_Tut_Random_Dot_Shark.png

Autostereogram Tutorial Random Dot Shark

- Description: Random dot stereogram showing a shark, to be watched with "wall-eyed"
- Source: Fred Hsu, March 2005.

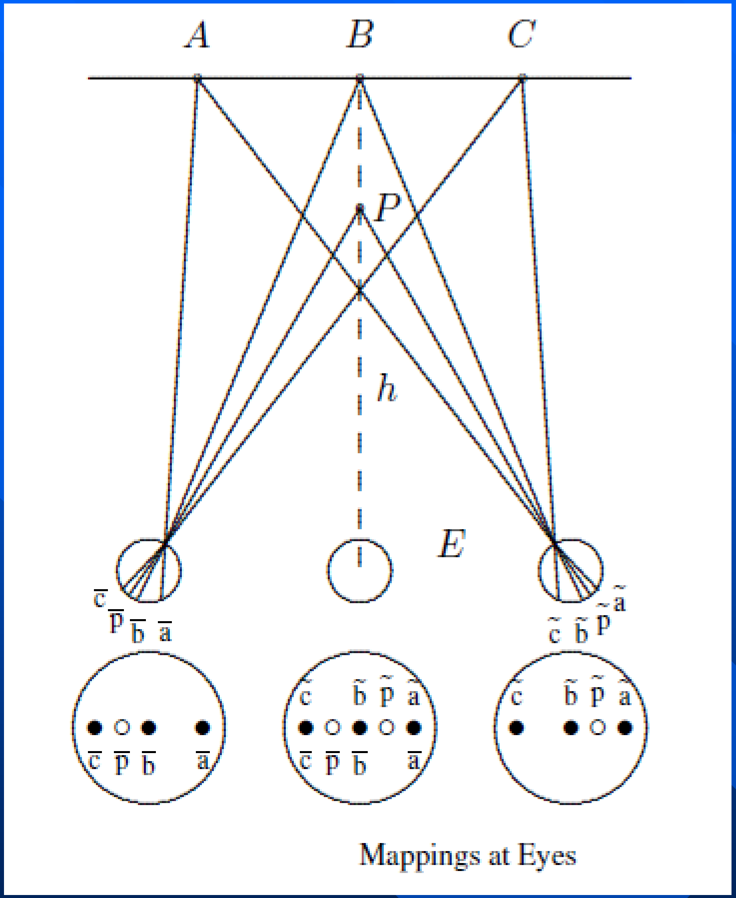
This random dot autostereogram encodes a 3D scene of a (colorfully dotted) shark swimming before a (colorfully dotted) background, like this:



It can be "seen" with proper "wall-eyed" viewing technique: the eyes have to be oriented as if focusing on an object behind the image, causing two neighboring repetition of the dot pattern to merge and the shark to appear.

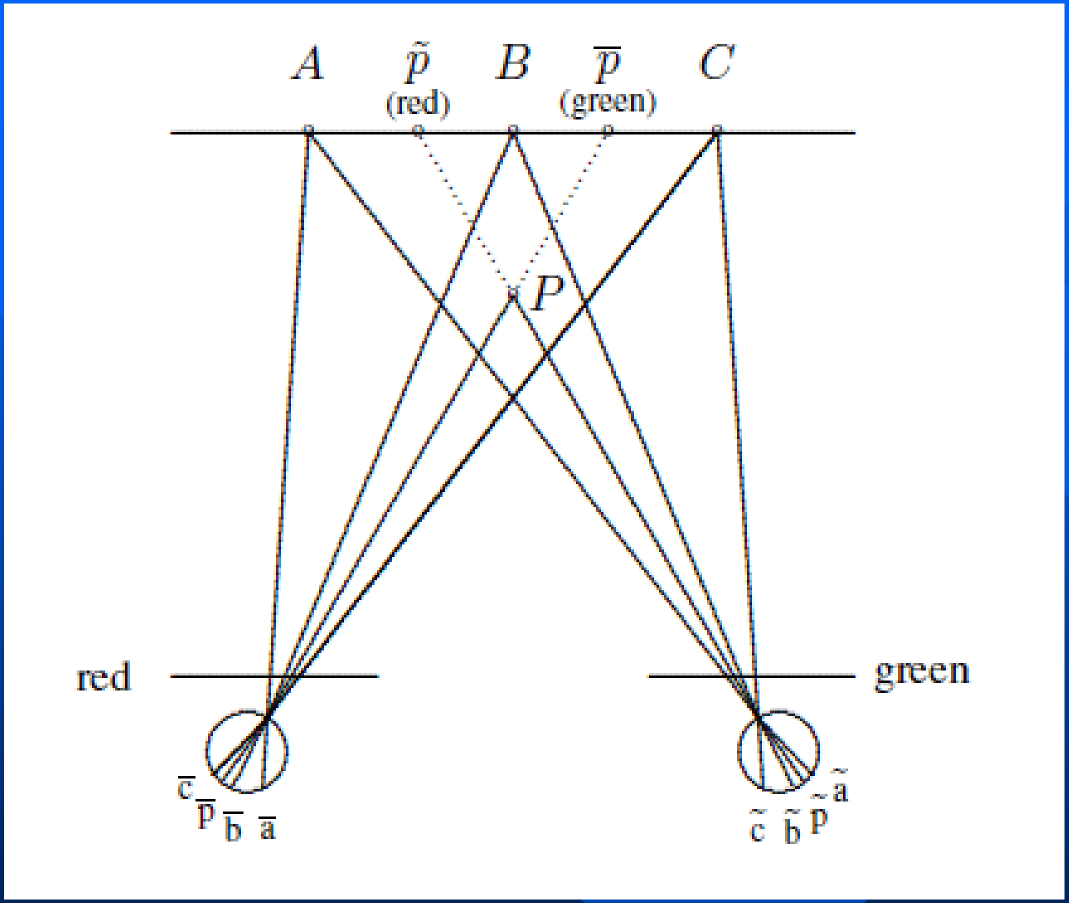
I, the copyright holder of this work, hereby publish it under the following licenses:

Natural Viewing



- Natural viewing of a point P that is located in front of a plane, compared to points A, B, and C that are located in a plane

3-D Viewing via Anaglyphs



- Viewing experience for anaglyphs where red and green filter glasses filter out what becomes invisible for each eye

History: Leonardo da Vinci's (1452-1519) Failure …

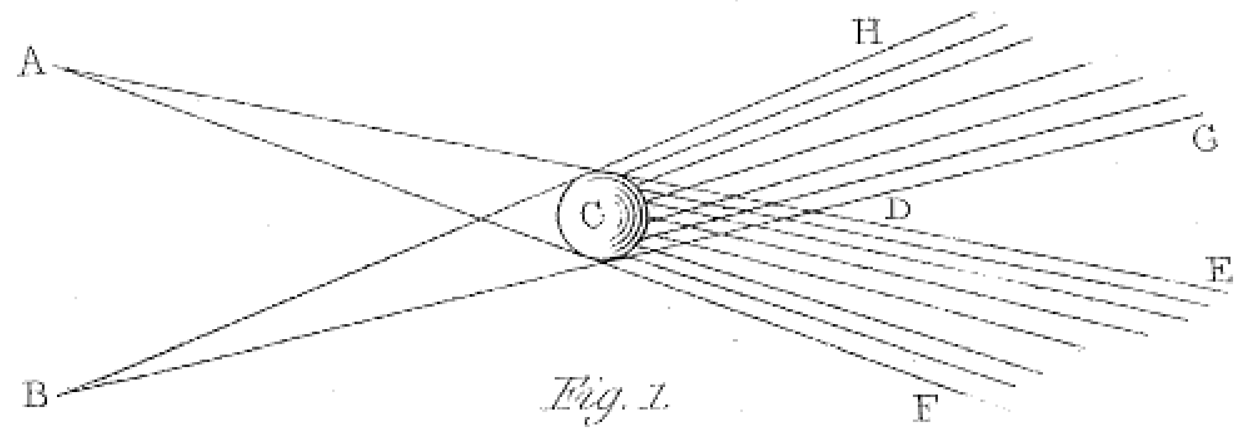


Fig. 1.

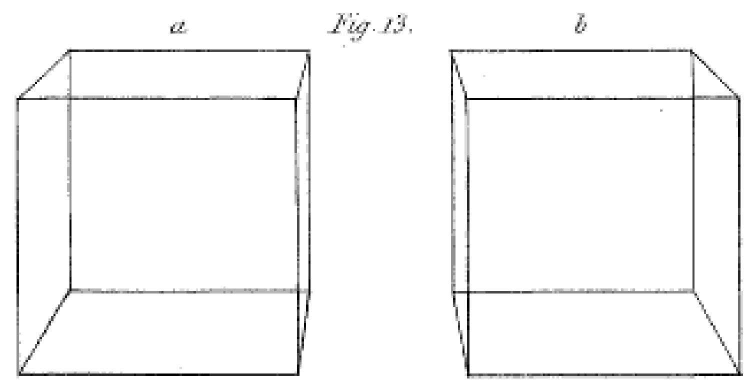
- Wheatstone (1838) explains:

Had Leonardo da Vinci taken, instead of a sphere, a less simple figure for the purpose of his illustration, a cube for instance, he would not only have observed that the object obscured from each eye a different part of the more distant field of view, but the fact would also perhaps have forced itself upon his attention, that the object itself presented a different appearance to each eye. He failed to do this, and no subsequent writer within my knowledge has supplied the omission; the projection of two

… is Wheatstone's Success (1838)

XVIII. *Contributions to the Physiology of Vision.—Part the First. On some remarkable, and hitherto unobserved, Phenomena of Binocular Vision.* By CHARLES WHEATSTONE, *F.R.S., Professor of Experimental Philosophy in King's College, London.*

Received and Read June 21, 1838.



each eye successively while the other is closed. Plate XI. fig. 13. represents the two perspective projections of a cube; *b* is that seen by the right eye, and *a* that presented to the left eye; the figure being supposed to be placed about seven inches immediately before the spectator.

Rollmann's (1853) Description of Anaglyphs

XII. *Zwei neue stereoskopische Methoden; von W. Rollmann.*

Zu der grofsen Zahl der schon bekannten, durch Wheatstone, Dove, Brewster und Wilde entdeckten, stereoskopischen Methoden habe ich folgende neue gefunden.

2. Farbenstereoskop, bestehend aus einer farbigen Doppelzeichnung und zwei gefärbten Gläsern.

Man zeichnet zwei zusammengehörige Körperansichten um *denselben* Mittelpunkt, die eine für das rechte, die andere für das linke Auge. Wenn es nun ein Mittel giebt,

More History on Anaglyphs (1)

- French teacher Joseph Charles d'Almeida (1858): used differently colored light to produce anaglyphs
- Name “anaglyps” introduced by the French Ducos du Hauron in 1891
- 1912: one of the first books dealing with anaglyphs (Vuibert, 1912)
- 1930/40ies: anaglyphs used in geometry (Koehler, Graf & Calov, 1938; Graf, 1938,1941)

More History on Anaglyphs (2)

- Burkhardt (1963, 1972, 1974) covered technical aspects and problems of printed anaglyphs such as optimal colors, best filter glasses, etc.
- Ideses and Yaroslavsky (2004, 2005) presented new methods how to improve the visual appearance of anaglyphs

I Ideses and L Yaroslavsky

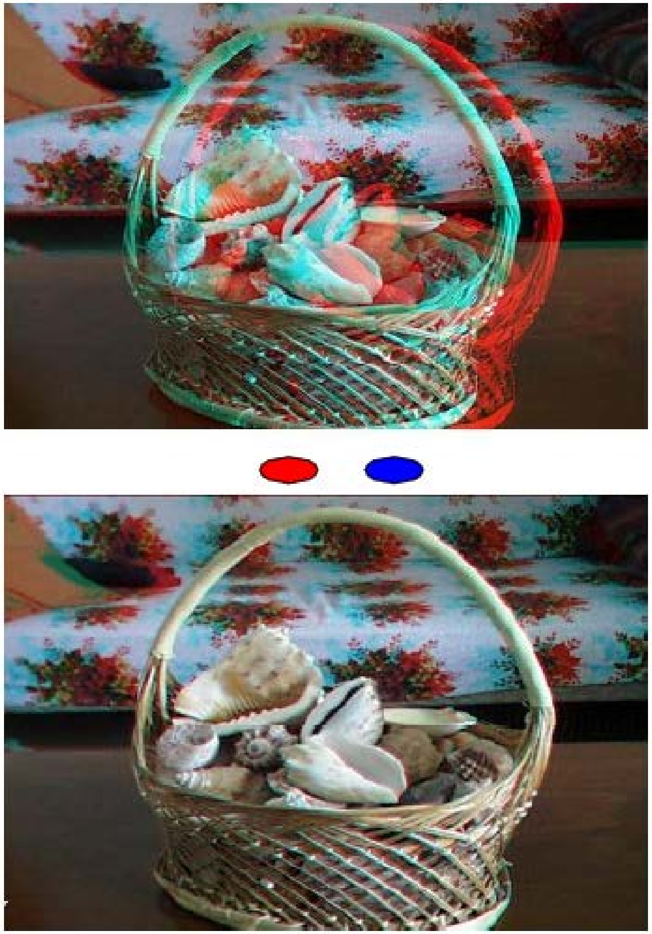


Figure 5. Standard colour anaglyph without image registration (top image) and anaglyph enhanced by means of image registration (bottom image). Note the reduced ghosting artefacts in the enhanced anaglyph. Use the red filter for the left eye and the blue filter for the right eye.

Mathematical Calculations (1)

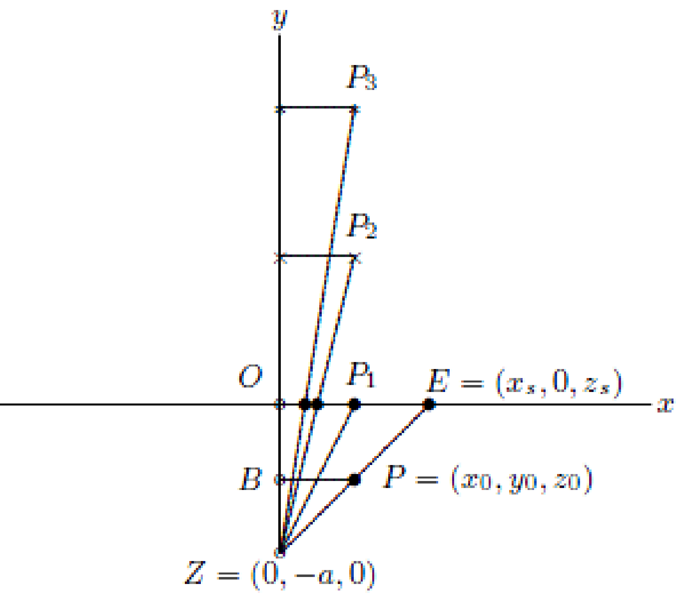


Figure 9: Projection for a single COP.

CRT coordinates (x_p, y_p)

$$\frac{|PB|}{|EO|} = \frac{|ZB|}{|ZO|} \Leftrightarrow |EO| = |PB| \cdot \frac{|ZO|}{|ZB|}$$

Therefore

$$x_p = x_s = x_0 \cdot \frac{a}{y_0 + a}.$$

By analogy (as projection into the zy plane)

$$y_p = z_s = z_0 \cdot \frac{a}{y_0 + a}$$

Mathematical Calculations (2)

Here

$$|E_lO_l| = |PB_l| \cdot \frac{|Z_lO_l|}{|Z_lB_l|} = \left|\left(x_0 + \frac{d}{2}\right) \cdot \frac{a}{y_0 + a}\right|$$

and

$$|E_rO_r| = |PB_r| \cdot \frac{|Z_rO_r|}{|Z_rB_r|} = \left|\left(x_0 - \frac{d}{2}\right) \cdot \frac{a}{y_0 + a}\right|$$

Therefore

$$x_{l_p} = \left(x_0 + \frac{d}{2}\right) \cdot \frac{a}{y_0 + a} - \frac{d}{2},$$

$$x_{r_p} = \left(x_0 - \frac{d}{2}\right) \cdot \frac{a}{y_0 + a} + \frac{d}{2},$$

$$y_{l_p} = y_{r_p} = y_p = z_0 \cdot \frac{a}{y_0 + a}.$$

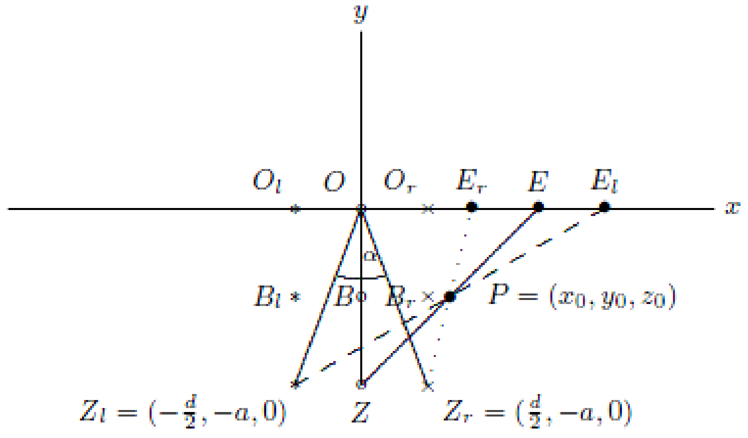


Figure 10: Projection for two COPs. Subscripts $_l$ and $*$ relate to the left eye, subscripts $_r$ and $\times$ relate to the right eye, and no subscript and $\circ$ relate to the imaginary central eye.

Applications in Statistics: Then … (1)

- Freeviewing of side-by-side images:

Huber (1987)

Huber: Experiences With Three-Dimensional Scatterplots 449

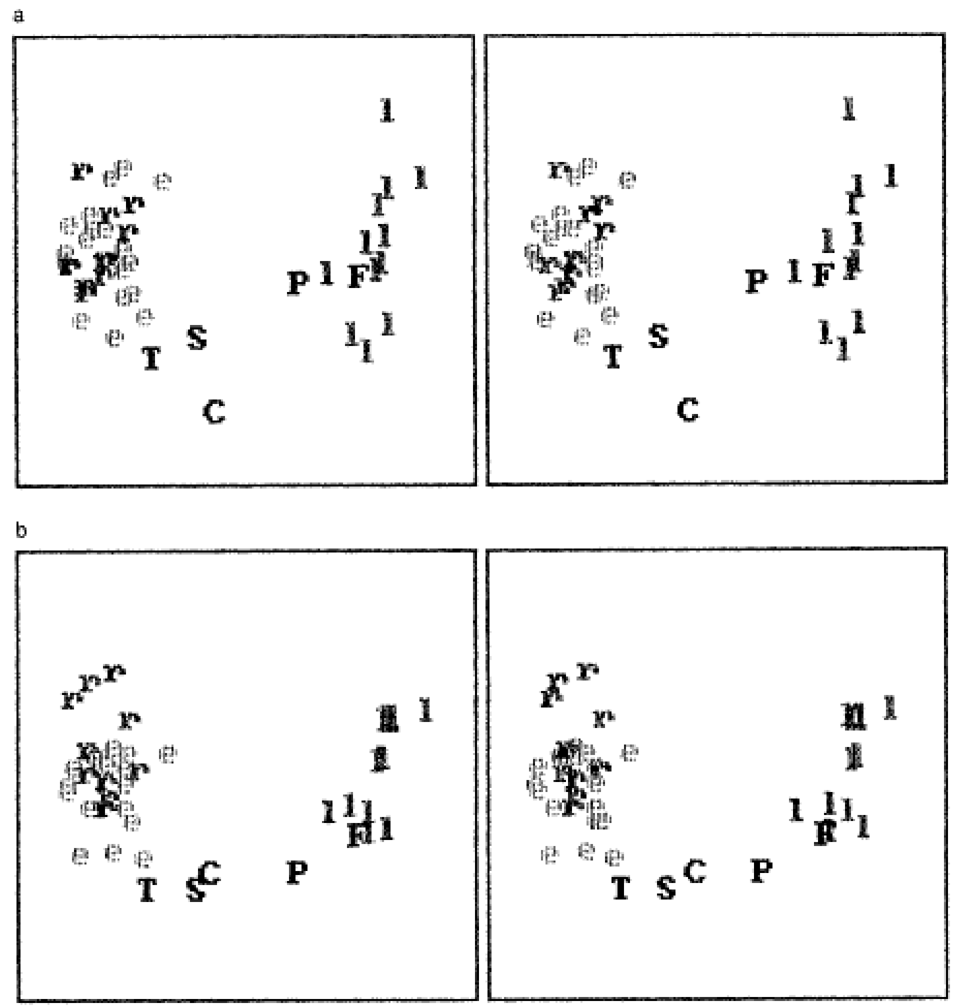


Figure 1. Results of a Principal Component Analysis of the Plato Sentence-Ending Data: First Three Principal Scores (a) Viewed Along the Third Principal Axis and (b) Rotated by 45° Around the First Axis. r—the books of the Republic; e—the other early works; l—the laws; T—Timaeus; S—Sophist; C—Critias; P—Politicus; F—Philebus.

Applications in Statistics: Then … (2)

- Freeviewing of side-by-side images:

Henderson (1989)

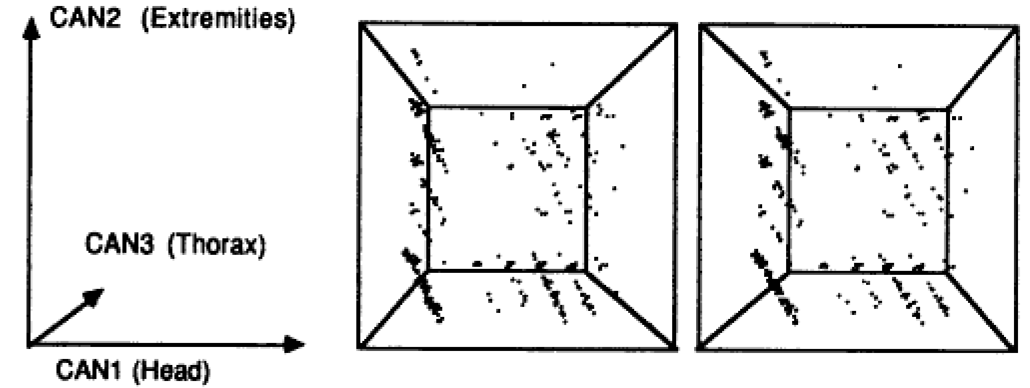


Figure 2. Stereoscopic scatter plot of first three canonical functions, canonical discriminant analysis of 336 WDMET wound patterns.

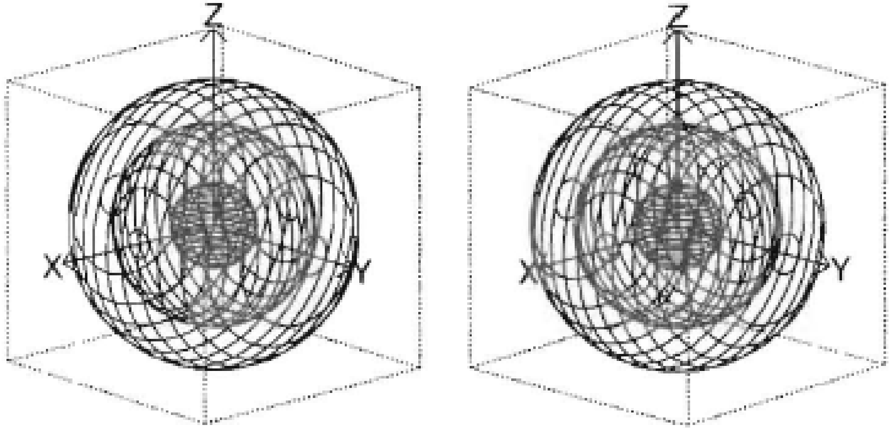


Figure 1.17 Stereo representation of 3 α−contours of a trivariate Normal density. Gently crossing your eyes should allow the 2 frames to fuse in the middle.

Scott (1992)

Applications in Statistics: Then … (3)

- Anaglyphs:
  - Extensively used within statistics by Carr, Littlefield, and Nicholson (1983-1986): provided construction details for 3–d stereoscopic displays and compared such displays with other visualization techniques for low–dimensional multivariate data sets
  - Work by Hering, Symanzik, and von der Weydt (1989-1994): developed computer software to interactively animate anaglyph images for multivariate statistical applications

Applications in Statistics: Then … (4)

- Anaglyphs:

PLATE 1 *(Banchoff)*

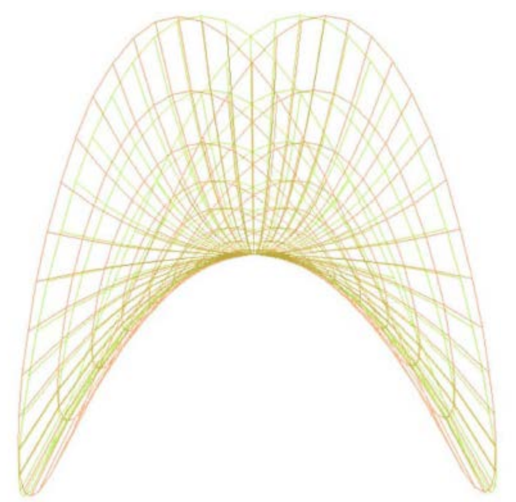


Figure 2

Banchoff (1986)

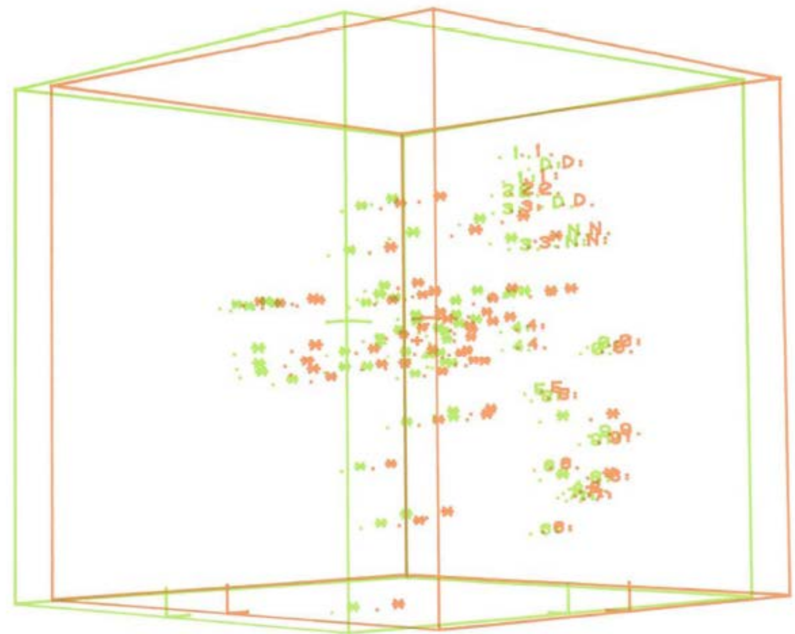


Figure 5 Three-dimensional biplot of American temperature data.

Gabriel & Odoroff (1986)

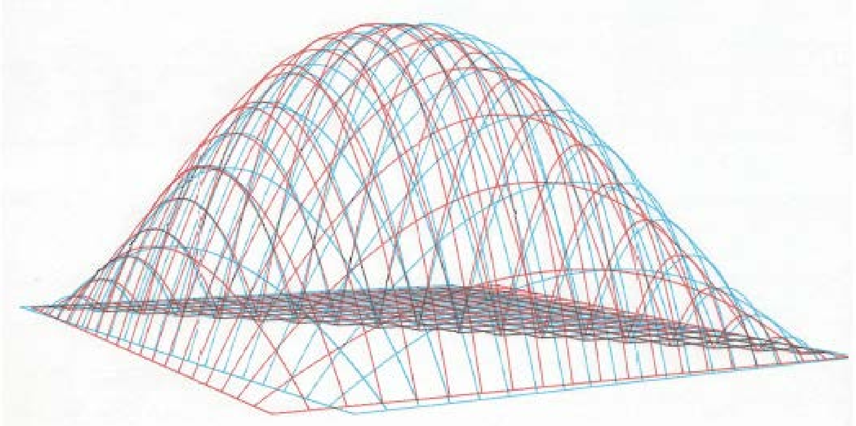


Bild 3: Bivariate Beta-Verteilung

Symanzik (1992)

Applications in Statistics: Then … (5)

- Anaglyphs:

Carr, Nicholson, Littlefield & Hall (1986)

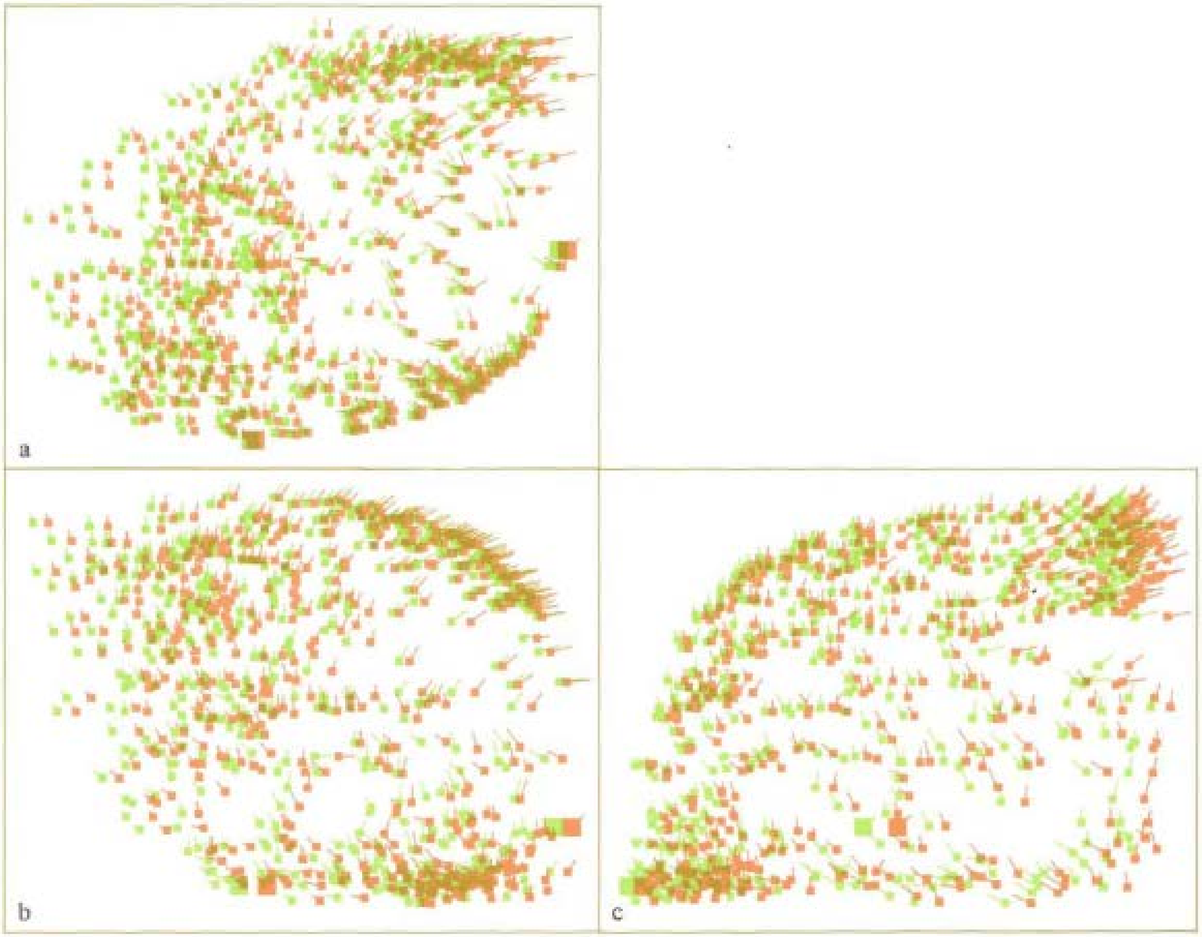


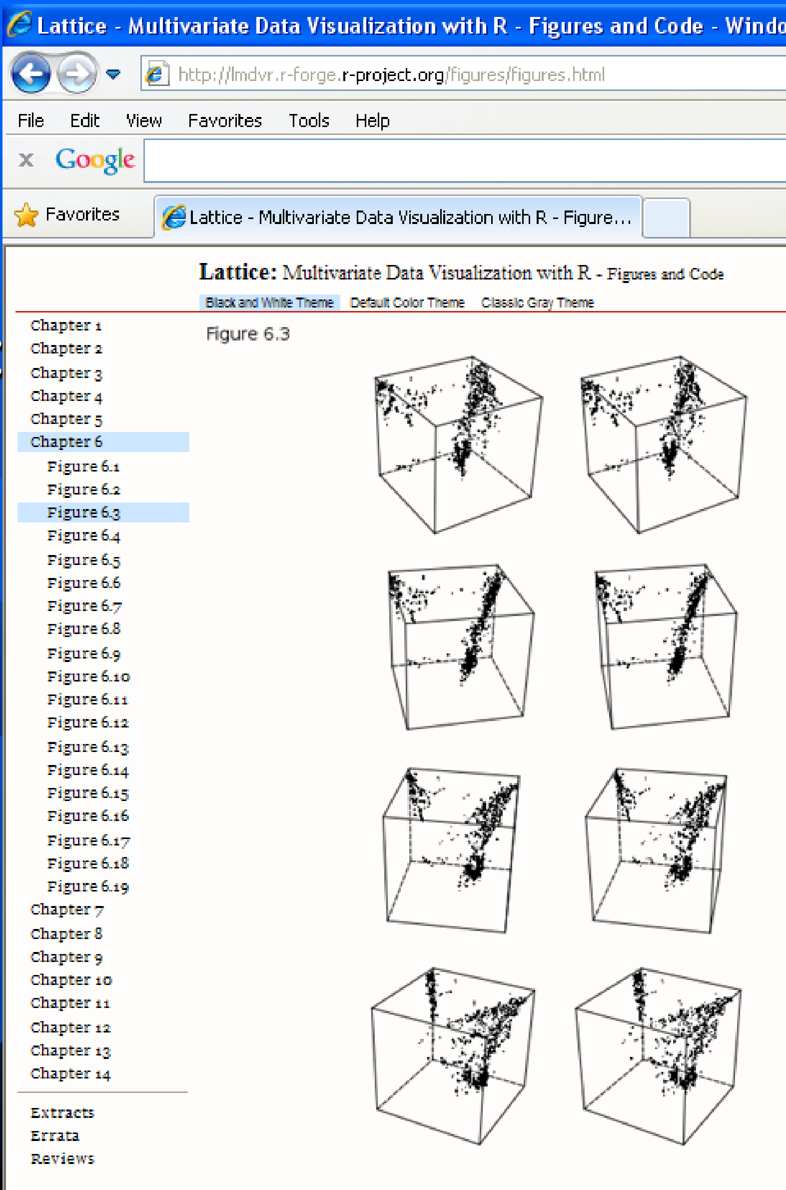
Exhibit 13 Five-dimensional views using stereo ray glyphs. The plot shows three views of five variables, V1, V3, V4, V5, and V7, that partially describe individual replications of a high-energy particle physics scattering experiment (Friedman and Tukey 1974). Exhibit 13b plots V1 as abscissa, V3 as ordinate, and V5 as stereo depth. Exhibit 13a is the view looking into Exhibit 13b from exterior top. Exhibit 13c is the view looking into Exhibit 13b from exterior right. All three views plot V7 as ray orientation and V4 as ray length. Two reference points are plotted with larger ray dots.

Applications in Statistics: … & Now (1)

- Freeviewing of Side-by-Side Images:
  - R package lattice (Sarkar 2008):

```
p <-
   cloud(depth ~ long + lat, quakes, zlim = c(690, 30),
        pch = ".", cex = 1.5, zoom = 1,
        xlab = NULL, ylab = NULL, zlab = NULL,
        par.settings = list(axis.line = list(col = "transparent")),
        scales = list(draw = FALSE))
npanel <- 4
rotz <- seq(-30, 30, length = npanel)
roty <- c(3, 0)

## Figure 6.3
update(p[rep(1, 2 * npanel)],
      layout = c(2, npanel),
      panel = function(..., screen) {
         crow <- current.row()
         ccol <- current.column()
         panel.cloud(..., screen = list(z = rotz[crow],
                                        x = -60,
                                        y = roty[ccol]))
      })
```



Applications in Statistics: … & Now (2)

- Anaglyphs:
  - R packages tourr & tourrGui (Cook, Wickham, Huang, Buja, 2011):

```
render(iris[, 1:4], grand_tour(3),
  display_stereo(blue = rgb(0, 0.91, 0.89),
    red = rgb(0.98, 0.052, 0)),
  "pdf", "Iris_Tour_R.pdf", frames = 200)
```

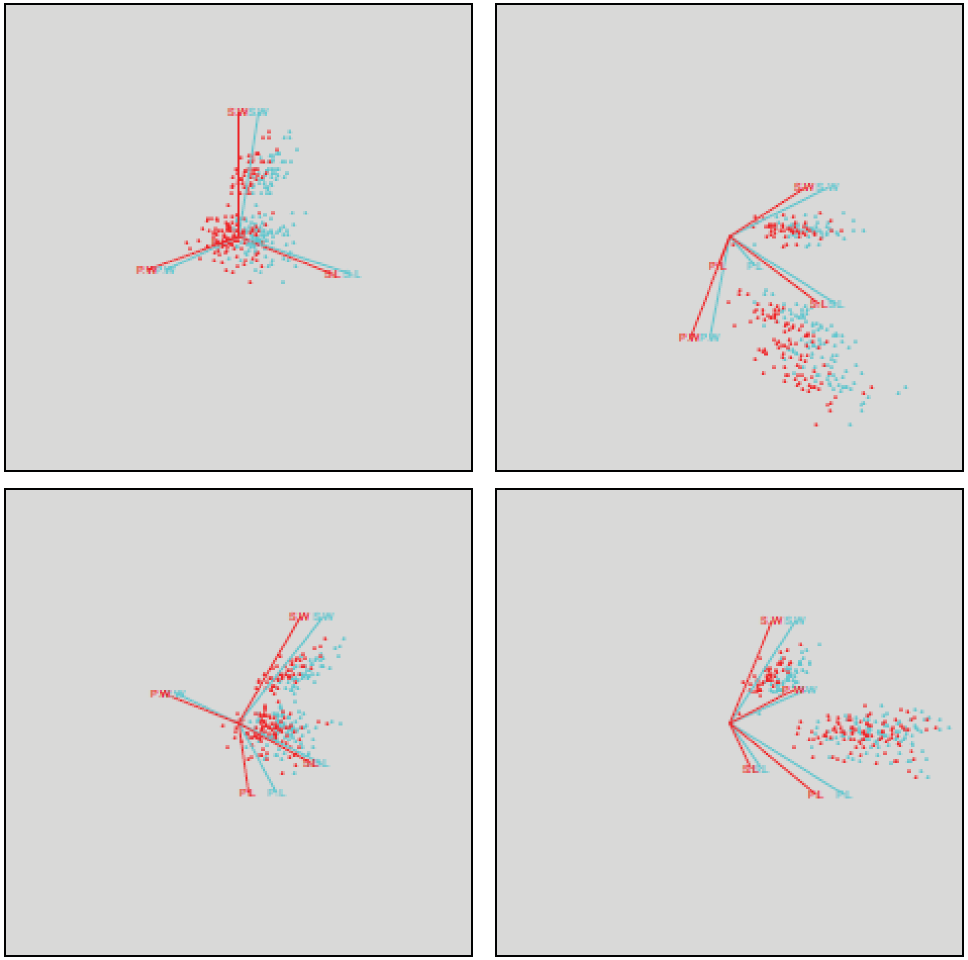
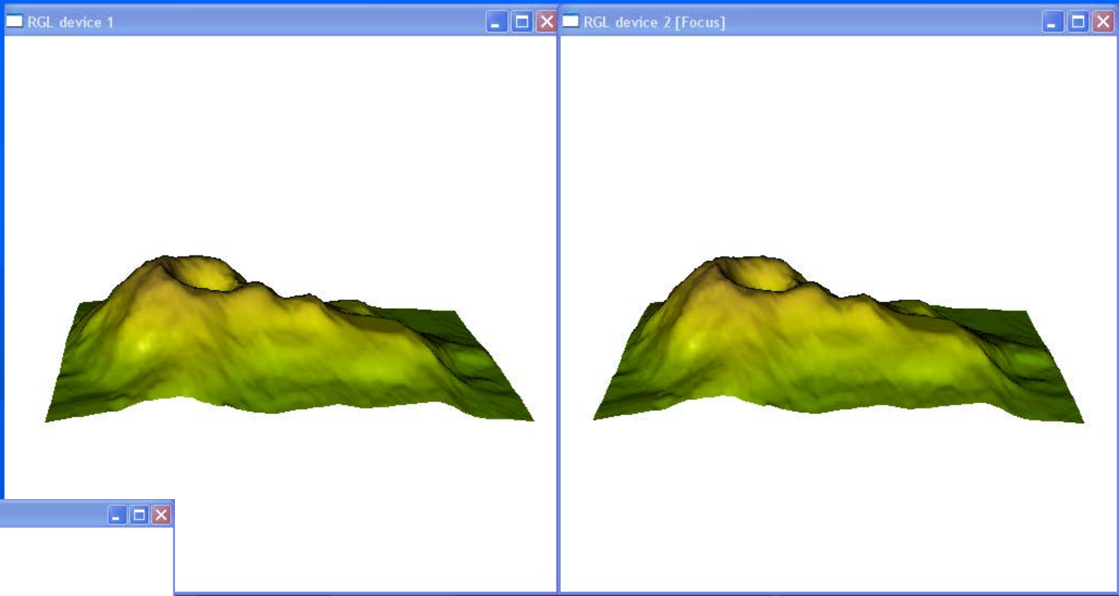
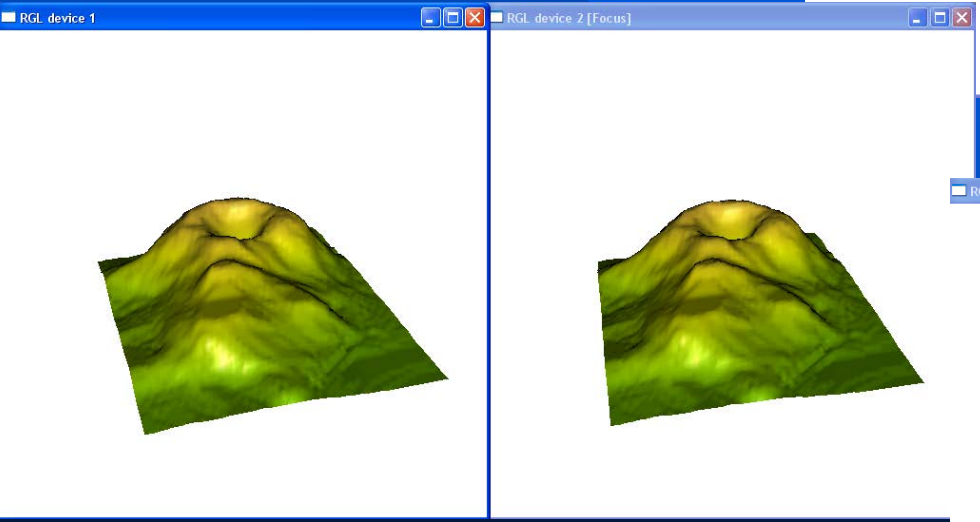


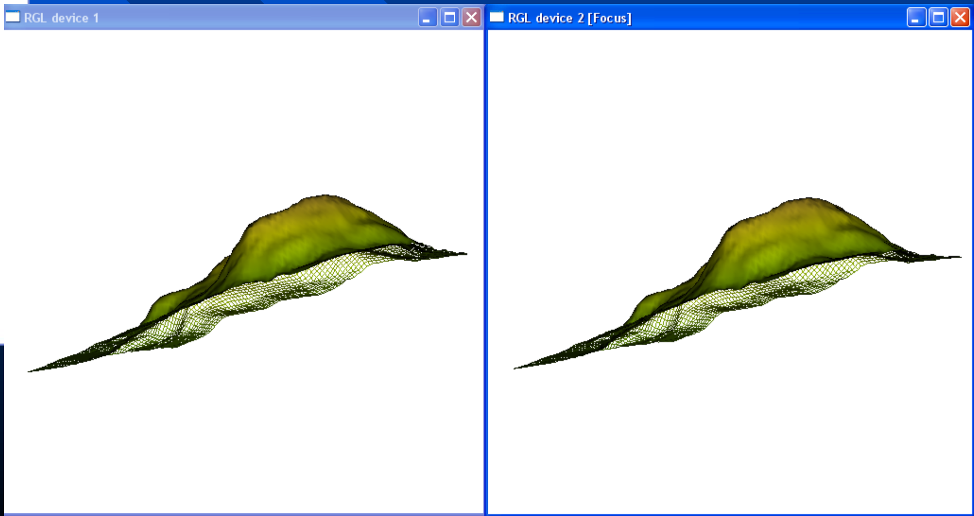
Figure 7: Four different projections of the 3–d grand tour of the Iris data set, shown as red–cyan anaglyphs, were produced via the `tourr` package in R. The abbreviations SL (Sepal Length), SW (Sepal Width), PL (Petal Length), and PW (Petal Width) are used in these plots to denote the four variables of the Iris data set.

Applications in Statistics: … & Now (3)

- Freeviewing:
  - R package rgl (Adler & Murdoch, 2011):



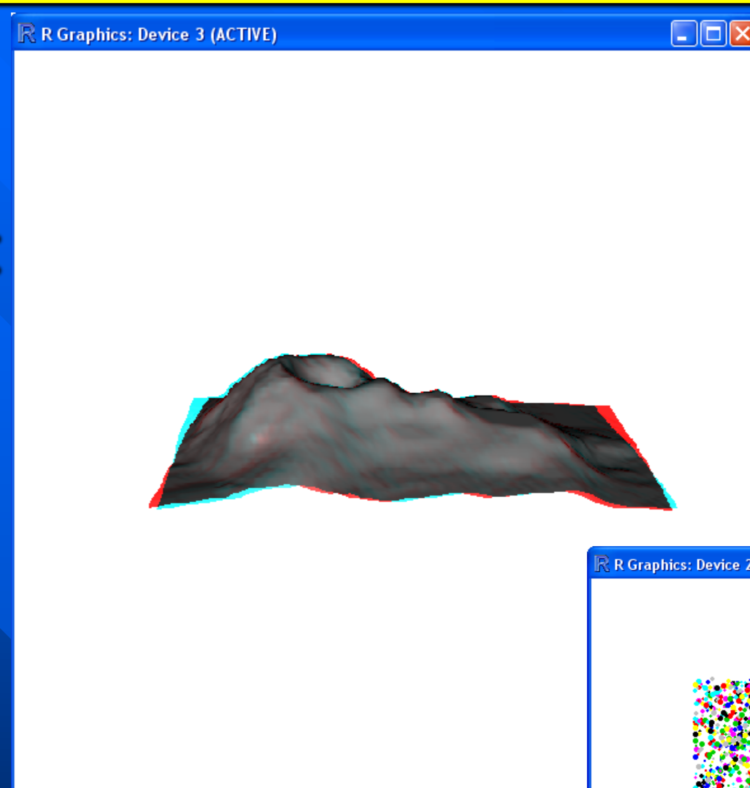


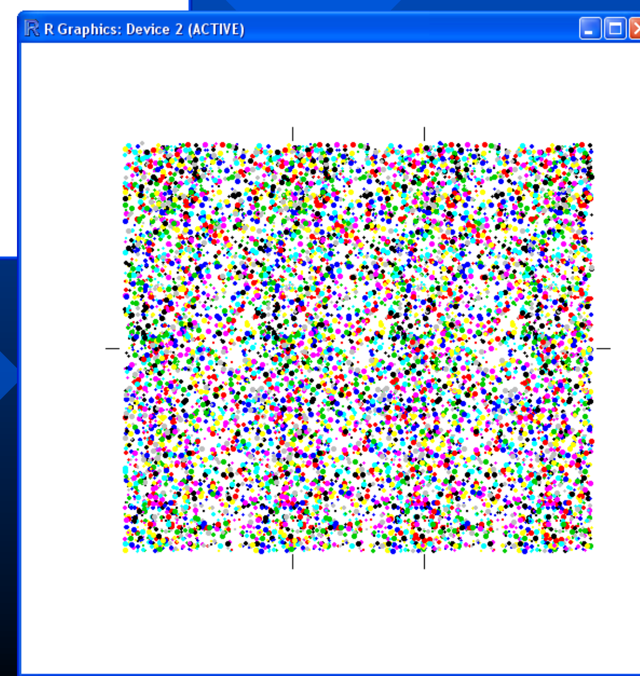



```
> demo("mouseCallbacks")
```

Applications in Statistics: … & Now (4)

- Anaglyphs & Autostereograms:
  - R package rgl (Adler & Murdoch, 2011):






```
> demo("stereo")
```

Conclusions & Outlook

- 3-D movies (such as Avatar & Toy Story 3) fascinated millions of spectators world-wide
- Leisure books with autostereograms (e.g., Magic Eye series) widely popular since the mid-1990ies
- 3-D TVs and convergence of TVs and computer monitors
- => 3-D stereoscopic graphics (via anaglyphs and others) likely to gain more popularity in statistics in the near future

References

- Symanzik J. Computerdarstellungen von Anaglyphen—Ein Hilfsmittel der multivariaten Statistik, Diplomarbeit, Fachbereich Informatik, Universität Dortmund, 1992.
- Symanzik, J. (1993A): Anaglyphen 3D - A Program for the Interactive Representation of Three-Dimensional Perspective Plots of Statistical Data, In: Opitz, O., Lausen, B., Klar, R. (Eds.), Information and Classication. Concepts, Methods and Applications. Proceedings of the 16th Annual Conference of the Gesellschaft fuer Klassikation e. V., Springer-Verlag, Berlin, Heidelberg, 384-389.
- Symanzik, J. (1993B): Three-Dimensional Statistical Graphics based on Interactively Animated Anaglyphs, 1993 Proceedings of the Section on Statistical Graphics, American Statistical Association, Alexandria, Virginia, 71-76.
- Symanzik, J. (2011): Three-Dimensional Stereoscopic Plots, Wiley Interdisciplinary Reviews (WIREs): Computational Statistics, Vol. 3, No. 6, 483-496.

Further Reading (1)

- Adler D, Murdoch D. rgl: 3D Visualization Device System (OpenGL), 2011. R package version 0.92.798.
- Banchoff TF. Visualizing two-dimensional phenomena in four-dimensional space: a computer graphics approach. In: Wegman EJ, DePriest DJ, eds. *Statistical Image Processing and Graphics*. New York, NY: Marcel Dekker; 1986, 187–202.
- Burkhardt R. Untersuchungen zur Verbesserung von Anaglyphenbildern. *Bildmessung Luftbildwesen* 1963, 31:190–195.
- Burkhardt R. Die farbliche Bemessung von Anaglyphenbrillen. *Die Farbe* 1972, 21:26–32.
- Burkhardt R. Studie über Anaglyphen-Druckfarben. *Die Farbe* 1974, 23:161–172.
- Carr DB, Littlefield RJ. Color anaglyph stereo scatterplots—construction details. In: Gentle JE, ed. *Proceedings of the 15th Symposium on the Interface between Computer Science and Statistics*. New York, NY: North-Holland Publishing Company; 1983, 295–299.
- Carr DB, Littlefield RJ, Nicholson WL. Color anaglyph stereo scatterplots—construction and application. *1983 Proceedings of the Section on Statistical Computing*. Alexandria, VA: American Statistical Association; 1983, 255–257.
- Carr DB, Nicholson WL, Littlefield RJ, Hall DL. Interactive color display methods for multivariate data. In: Wegman EJ, DePriest DJ, eds. *Statistical Image Processing and Graphics*. New York, NY: Marcel Dekker; 1986, 215–250.
- d'Almeida JC. Nouvel Appareil Stéréoscopique. *Comptes rendus des séances l'Académie Sci* 1858, XLVII:61–63.
- Gabriel KR, Odoroff CL. Illustrations of model diagnosis by means of three-dimensional biplots. In: Wegman EJ, DePriest DJ, eds. *Statistical Image Processing and Graphics*. New York, NY: Marcel Dekker; 1986, 257–274.
- Graf U. *Sphärische Geometrie, Trigonometrie der Ebene und Kartenentwürfe*. Leipzig: Quelle & Meyer; 1938.
- Graf U. Konstruierte Anaglyphen. *Bildmessung Luftbildwesen* 1941, 16:59–66, published as a supplement to *Allgemeine Vermessungs–Nachrichten* 53.

Further Reading (2)

- Henderson JV. Cluster analysis and rotating 3-D scatterplots to explore and link a multimedia trauma data base. Proceedings of the Annual Symposium on Computer Application in Medical Care, November 8, 1989, 392–398.
- Hodges LF. Tutorial: time-multiplexed stereoscopic computer graphics. *IEEE Comp Graph Appl* 1992, 12(2):20–30.
- Huang B, Cook D, Wickham H. tourrGui: A Tour GUI Using gWidgets, 2011. R package version 0.2.
- Huber PJ. Experiences with three-dimensional scatterplots. *J Am Stat Assoc* 1987, 82:448–453.
- Ideses I, Yaroslavsky L. New methods to produce high quality color anaglyphs for 3-D visualization. In: Campilho A, Kamel M, eds. *Image Analysis and Recognition, Lecture Notes in Computer Science*, Vol. 3212. Berlin: Springer; 2004, 273–280.
- Ideses I, Yaroslavsky L. Three methods that improve the visual quality of colour anaglyphs. *J Opt A: Pure Appl Opt* 2005, 7:755–762.
- Köhler O, Graf U, Calov C.*Mathematische Raumbilder*. Berlin: Dreyer; 1938.
- Rollmann W. Notiz zur Stereoskopie. *Ann Phys Chem* 1853, 89:350–351.
- Rollmann W. Zwei neue stereoskopische Methoden. *Ann Phys Chem* 1853, 90:186–187.
- Sarkar D. *Lattice: Multivariate Data Visualization with R*. New York, NY: Springer; 2008.
- Scott DW. *Multivariate Density Estimation: Theory, Practice, and Visualization*. New York, NY: John Wiley & Sons; 1992.
- Vuibert H. *Les Anaglyphes Géométriques*. Paris: Librairie Vuibert; 1912.
- Wheatstone C. Contributions to the physiology of vision—part the first. On some remarkable, and hitherto unobserved, phenomena of binocular vision. *Phil Trans R Soc London* 1838, 128:371–394.
- Wickham H, Cook D, Hofmann H, Buja A. tourr: An R package for exploring multivariate data with projections. *J Stat Softw* 2011, 40.

Part II: Statistics and Virtual Reality at Iowa State University (1995-1997)

Contents

- Virtual Reality (VR)
- The C2 Virtual Reality Environment
- Dynamic Statistical Graphics (DSG) in the C2
- Unfinished Work (1997)

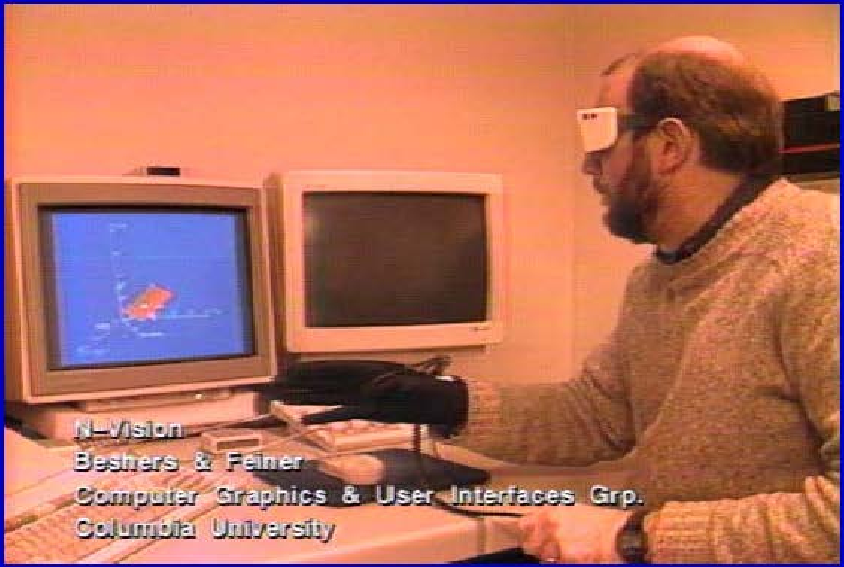
Virtual Reality (VR) - Definition

- Different understandings of the term VR:
  - Pimentel, Teixeira: "Virtual reality is the place where humans and computers make contact."
  - Newby: "VR has to do with the simulation of environments."
  - Anonymous: "Virtual reality is a media to recreate the world in which we live and to create illusions of new and yet unknown worlds."
  - Cruz−Neira: "Virtual reality refers to immersive, interactive, multi−sensory, viewer−centered, three−dimensional computer generated environments and the combination of technologies required to build these environments."

Virtual Reality (VR) - Terms

- Related Terms:
  - » Augmented Reality
  - » Artificial Reality
  - » Virtual Environments
  - » Cyberspace

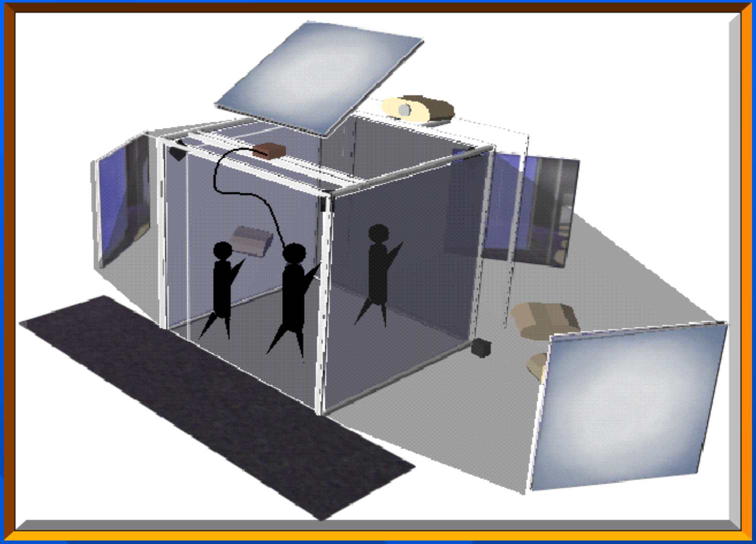
Virtual Reality (VR) - History



Immersive Environments - History

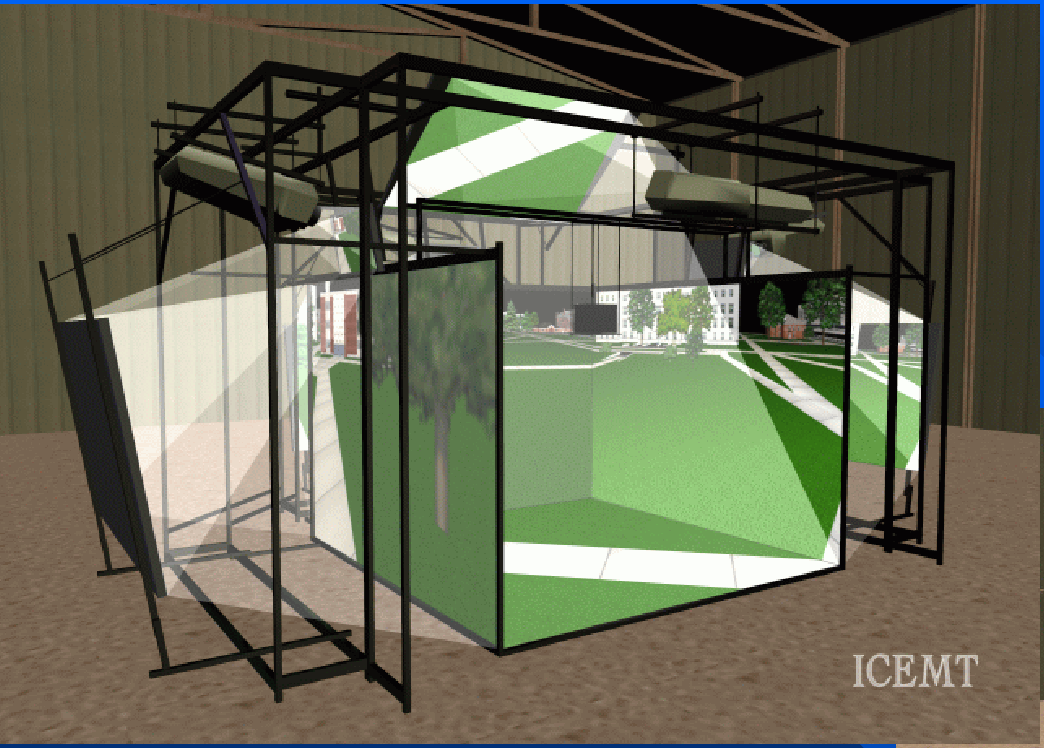
- 1991 CAVE: Electronic Visualization Laboratory, Univeristy of Illinois, Chicago
- 1996 C2: Iowa Center for Emerging Manufacturing Technology, Iowa State University, Ames

C2 – Technical Details

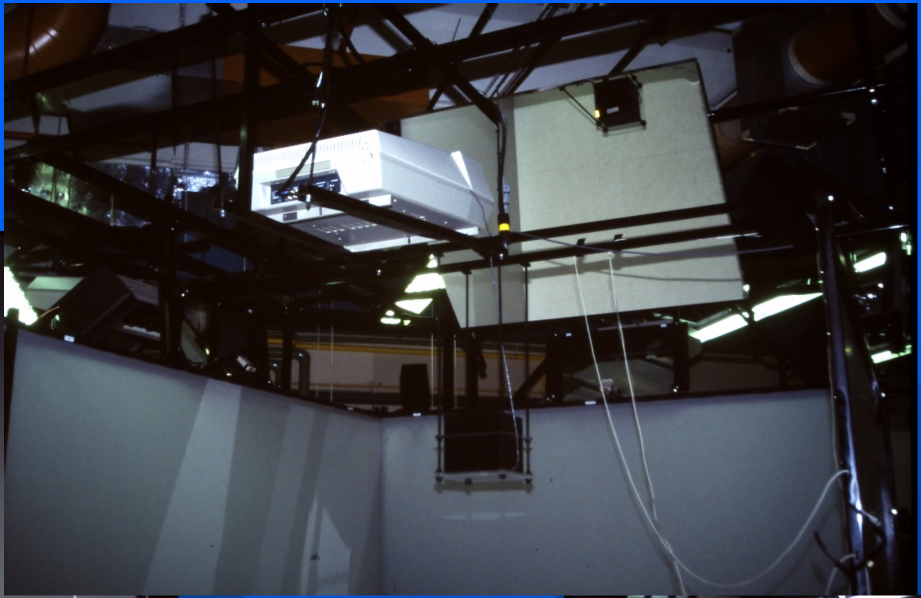


- Projection–based, uses
  - » 3D computer graphics
  - » Position tracking
  - » Auditory feedback
- Projections onto three side walls and floor
- Floor print of 12 x 12 feet
- Height of 9 feet

C2-Appearance (1)



C2-Appearance (2)



C2 – 3D Illusion

- Created through LCD shutterglasses and high–performance SGI graphics computers
- Alternating left and right eye viewpoints at 96hz
- User's brain combines two views into 3D stereoscopic image
- Position and orientation of user's hands and head determined through magnetic based tracker, cyberglove, and hand–held wand
- Audio feedback through multiple speakers

C2 vs. Other VR Devices

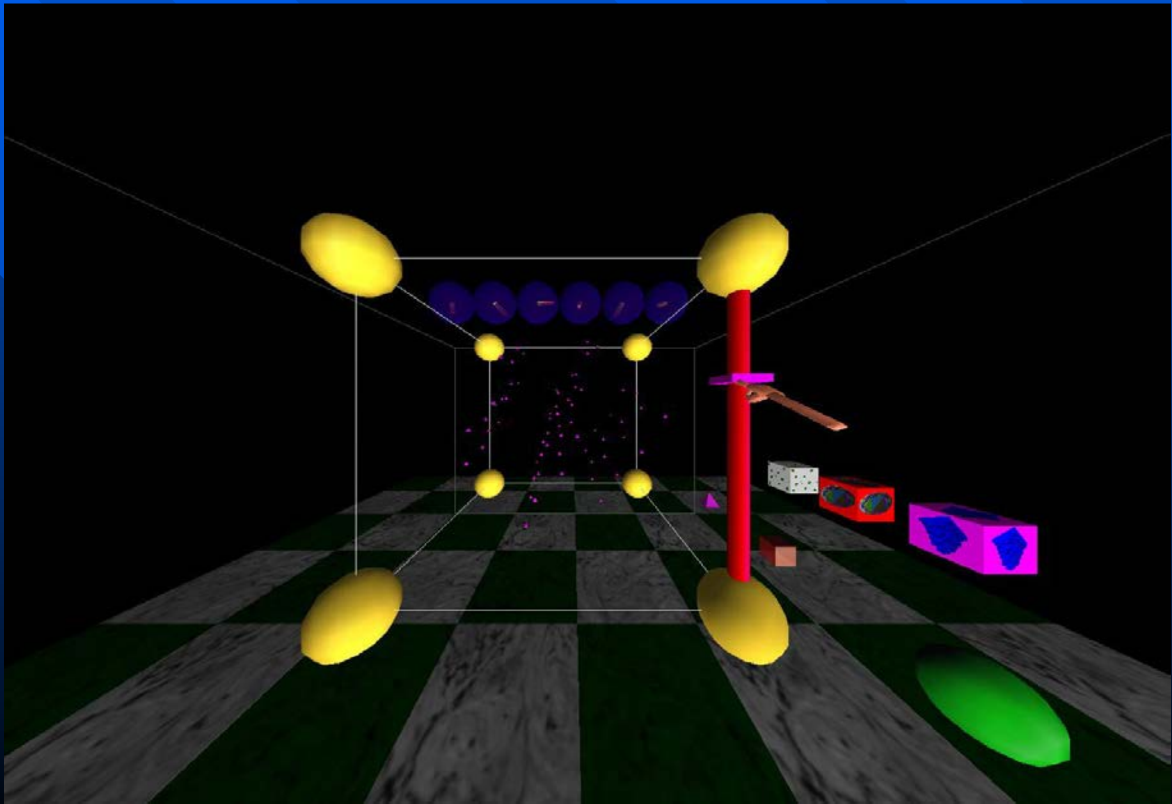
- Multiple viewers
- Lightweight and unrestrictive equipment
- High visual acuity, i.e., clarity of vision; depends on
  - » Optical factors
  - » Neural factors

DSG in the C2 - Concepts

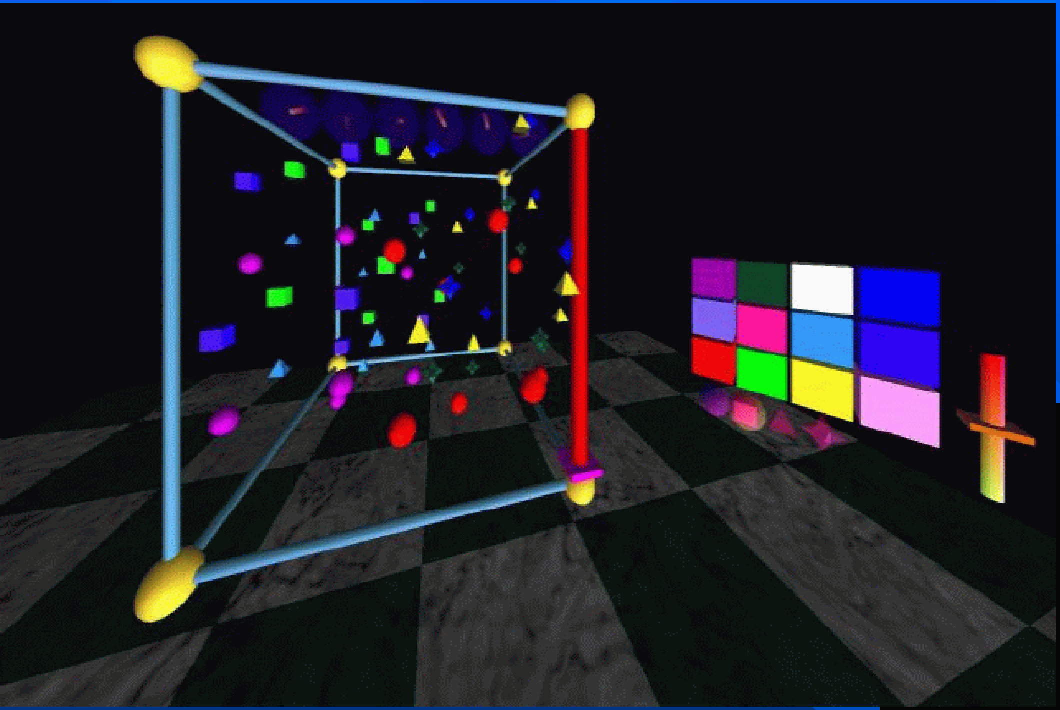
- 1–, 2–, or 3–dimensional projections of p–dimensional data
- Viewing data in form of point clouds or modeled surfaces
- Multiple views or continuous sequence of views
- New user interface
  - » Most DSG programs: like a desktop
  - » Immersive environment: whole room for data analysis

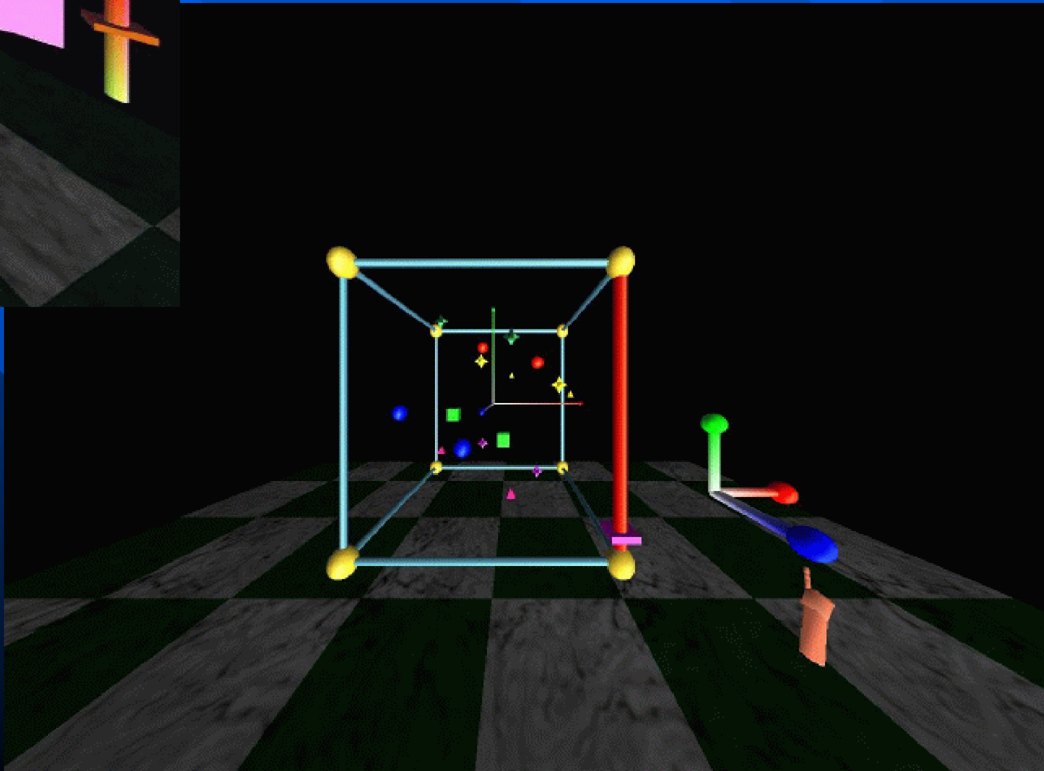
DSG in the C2 - Tools

- Viewing box
- Speed pole
- Variable spheres
- Goody boxes
- Glyph types



DSG in the C2 – Latest Design (1)





DSG in the C2 – Latest Design (2)

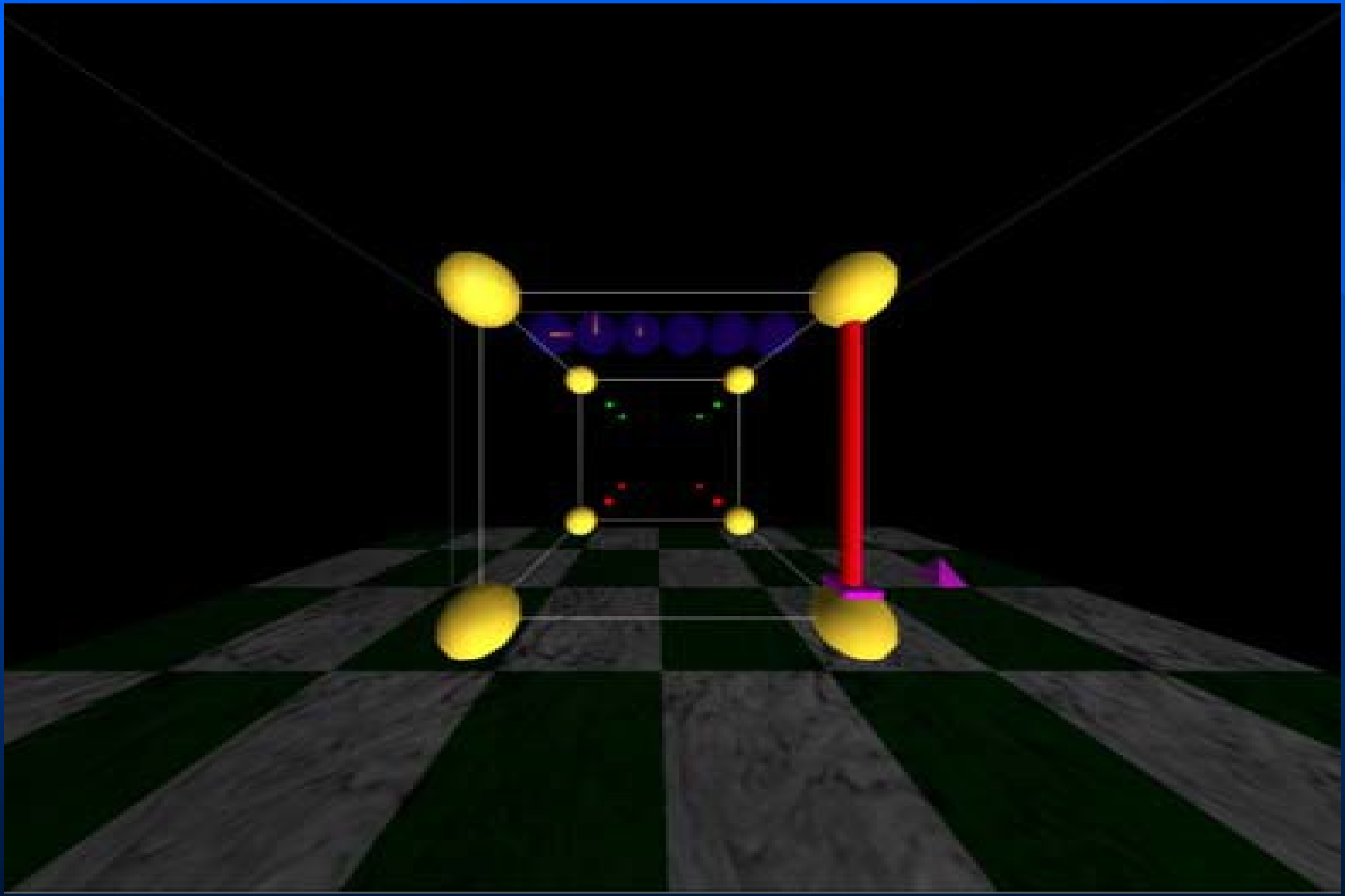
Show Video:

Interaction Tools for Dynamic Statistical Graphics in a Highly Immersive Environment.VOB

DSG in the C2 - Examples

- (Multiple) low–dimensional views
- High–dimensional rotation and interaction
- Brushing / linked brushing

3-dim Grand Tour of 6-dim Cube Example (1)

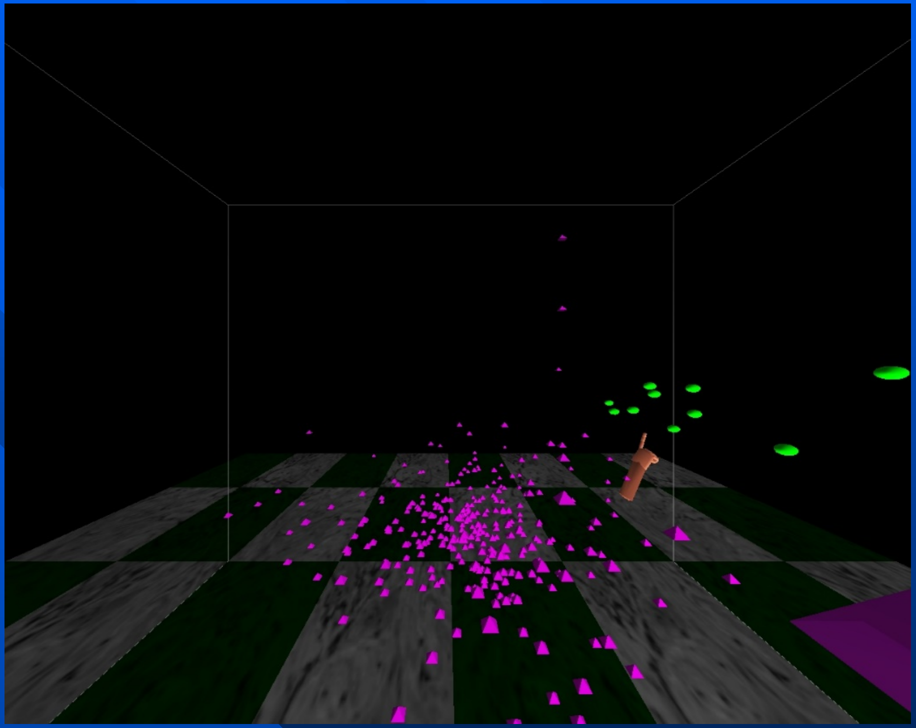


3-dim Grand Tour of 6-dim Cube Example (2)

Show Video:

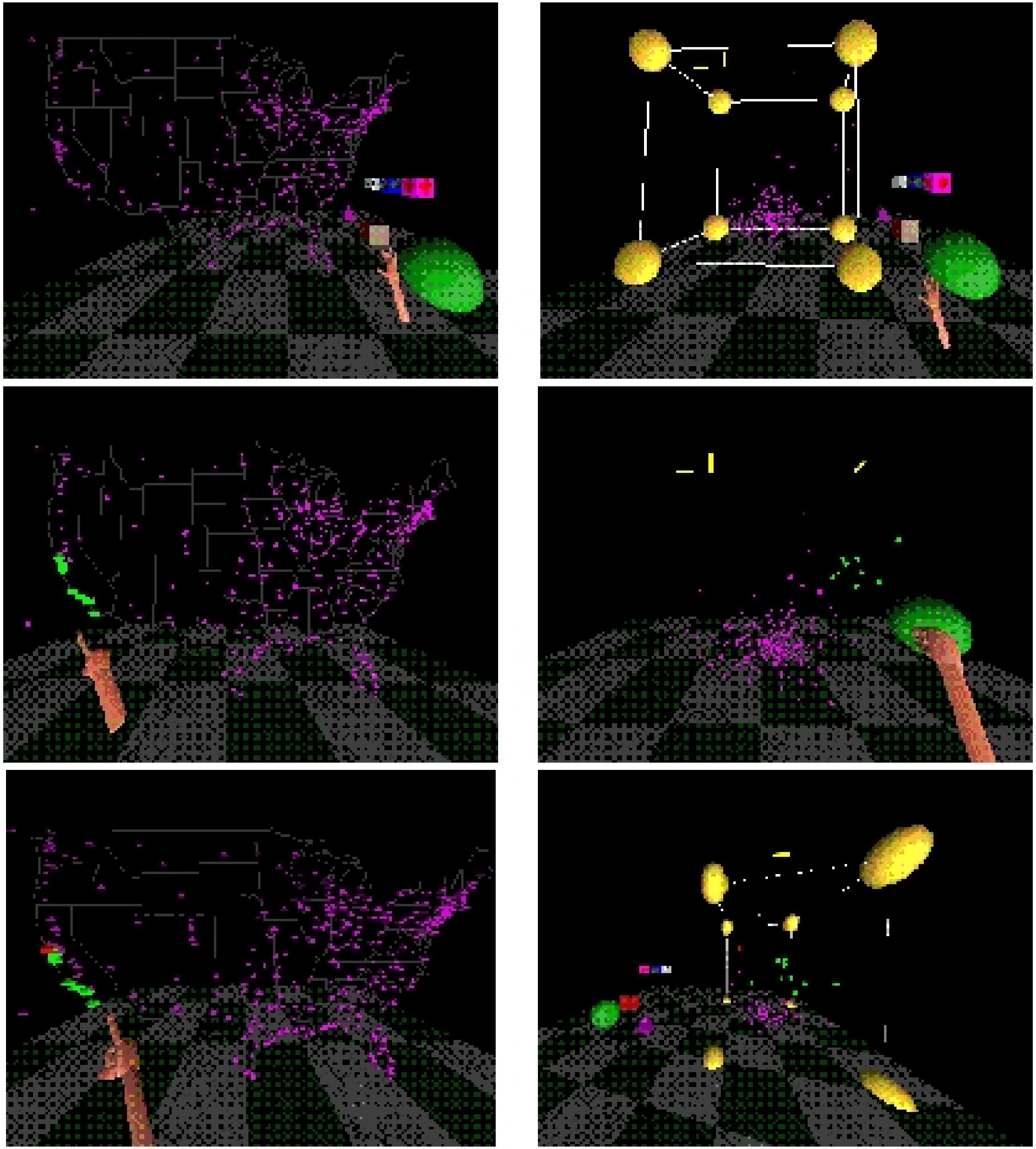
Dynamic Statistical Graphics in a Highly Immersive Environment.VOB (starting at 3:05min)

Map View Example (1)



Based on "Places Data" from Boyer & Savageau (1981)

Map View Example (2)



Map View Example (3)

Show Video:

Dynamic Statistical Graphics in a Highly Immersive Environment_People-Version.VOB

Environmental Example (1)

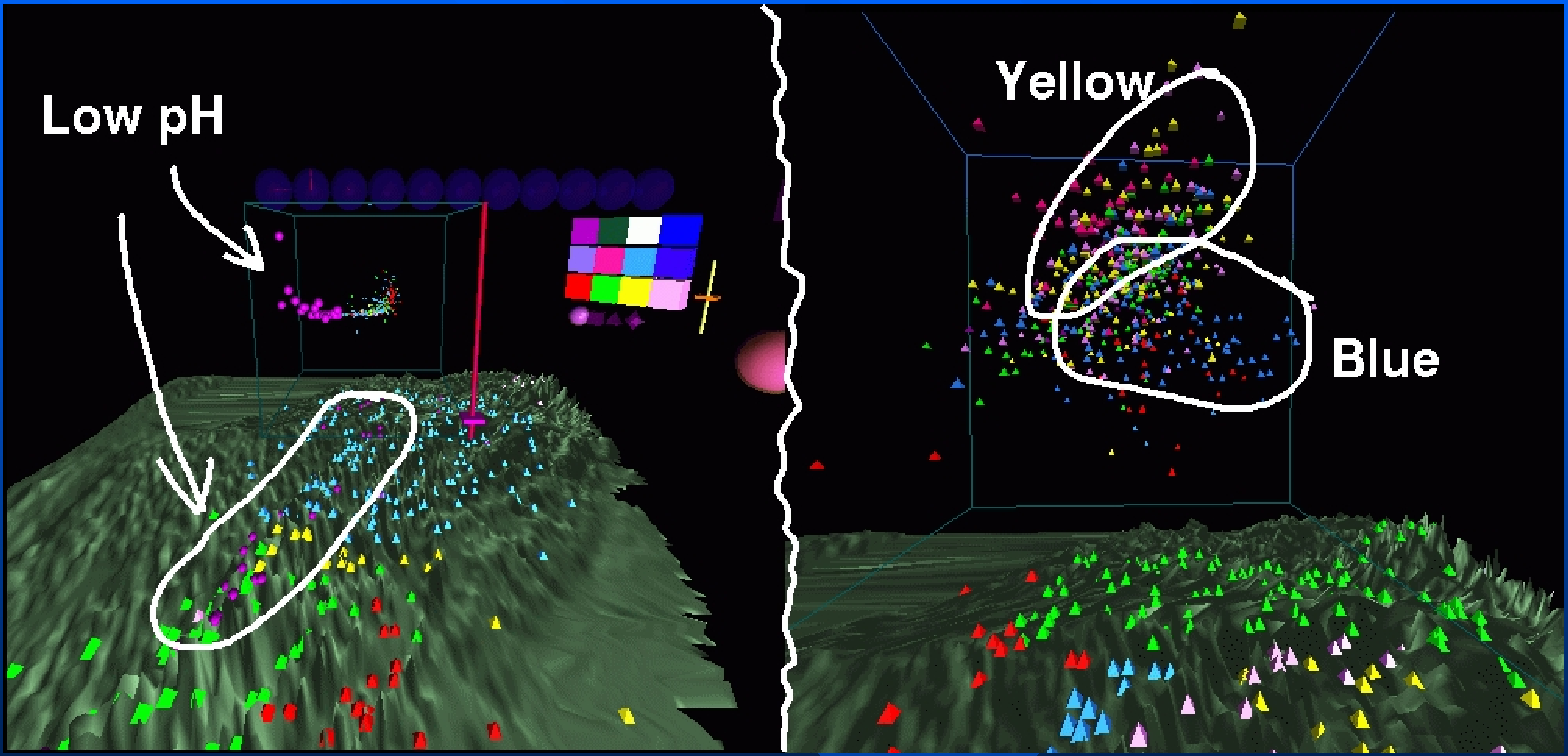


Fig. 4. In simulator mode: (left) Low pH values are brushed purple in the scatterplot, and these sampling sites which are more acidic fall higher up in the mountains. This corroborates what was seen in Figure 3 but in the C2 it is much easier to see the sites are at high altitude because the mountains are rendered in 3D. (right) Grand tour view over the elevation indicating differences in combination of chemical contaminants over ecoregion.

Environmental Example (2)

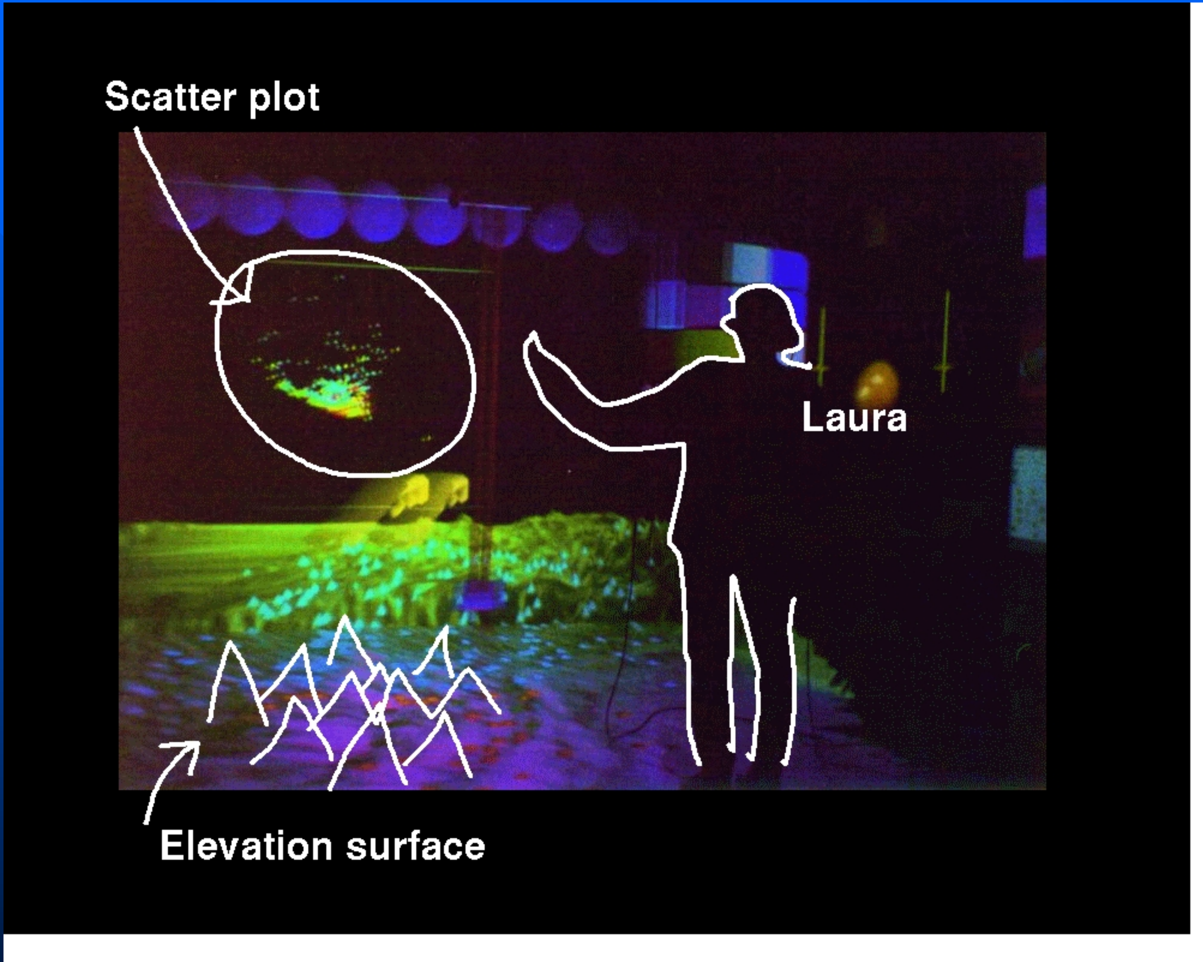


Fig. 5. The measurements on samples in streams of the mid-Atlantic states in the C2.

Unfinished Work (1997)

- 3D user interface for DSG
  - » 3D menus
  - » What to do with brushes
  - » How to place objects (e.g., maps)
  - » Sound (e.g., voice identification of points)
- Inclusion of maps and geographic information for spatial data (e.g., satellite images)
- Connections to supercomputers for processing of massive data

References

- Symanzik, J., Cook, D., Kohlmeyer, B. D., Lechner, U., Cruz-Neira, C. (1997): Dynamic Statistical Graphics in the C2 Virtual Reality Environment, Computing Science and Statistics, Vol. 29, No. 2, 41-47.
- Cook, D., Cruz-Neira, C., Lechner, U., Nelson, L., Olsen, A., Pierson, S., Symanzik, J. (1997): Using Dynamic Statistical Graphics in a Highly Immersive Virtual Reality Environment to Understand Multivariate (Spatial) Data, Bulletin of the International Statistical Institute, 51st Session Istanbul 1997, Proceedings Book 2, 31-34.
- Cook, D., Cruz-Neira, C., Kohlmeyer, B. D., Lechner, U., Lewin, N., Nelson, L., Olsen, A., Pierson, S., Symanzik, J. (1998): Exploring Environmental Data in a Highly Immersive Virtual Reality Environment, Environmental Monitoring and Assessment, Vol. 51, No. 1/2, 441-450.

Further Reading

- Cruz-Neira, C. (1993). Virtual Reality Overview. SIGGRAPH '93 Course Notes #23. pp. 1-18.
- Cruz-Neira, C. (1995). Projection-Based Virtual Reality: The CAVE and its Applications to Computational Science. PhD thesis, University of Illinois at Chicago.
- Cruz-Neira, C., Leigh, J., Papka, M., Barnes, C., Cohen, S. M., Das, S., Engelmann, R., Hudson, R., Roy, T., Siegel, L., Vasilakis, C., DeFanti, T., and Sandin, D. J. (1993a). Scientists in Wonderland: A Report on Visualization Applications in the CAVE Virtual Reality Environment. In IEEE 1993 Symposium on Research Frontiers in Virtual Reality, pages 59-66.
- Cruz-Neira, C., Sandin, D. J., DeFanti, T., Kenyon, R., and Hart, J. C. (1992). The CAVE, AudioVisual Experience Automatic Virtual Environment. Communications of the ACM, 35:64-72.
- Cruz-Neira, C., Sandin, D. J., and DeFanti, T. A. (1993b). Surround-Screen Projection-Based Virtual Reality: The Design and Implementation of the CAVE. In ACM SIGGRAPH '93 Proceedings, pages 135-142, Anaheim, CA.
- Pimentel, K. and Teixeira, K. (1995). Virtual Reality through the new Looking Glass (Second Edition). McGraw-Hill, New York, NY.
- Roy, T., Cruz-Neira, C., and DeFanti, T. A. (1995). Cosmic Worm in the CAVE: Steering a High Performance Computing Application from a Virtual Environment. Presence: Teleoperators and Virtual Environments, 4(2):121-129.
- Sutherland, I. E. (1965). The Ultimate Display. In Proc. IFIP 65, 2, pages 506-508, 582-583.

Part III: Statistics and Virtual Reality at George Mason University (1997-1999)

Contents

- The CAVE^{TM} VR Environment
- Motivation for the MiniCAVE^{TM}
- The MiniCAVE^{TM} Environment
  - – Windows NT/Pentium II Implementation
  - – Voice Interface
- Technical Challenges
- Status (as of 1999)

Trademark Notes

- CAVE is a trademark of the Electronic Visualization Laboratory at the University of Illinois, Chicago
- MiniCAVE is a trademark of the Center for Computational Statistics at George Mason University

CAVE Concept

- A Projection-based Immersive VR System
  - Silicon Graphics-based with 8 to 12 processors
  - RE^2 or RE Infinity graphics engines
  - CRT-based projection system
  - Stereographics Crystal Eyes shutter glasses
  - Head tracking
  - Usually 3 to 6 wall cube

CAVE Strengths

- Effective immersive environment
  - Lightweight non-intrusive glasses
  - Can see own hands and other participants
- Effective for group VR
  - Good tool for group collaboration

CAVE Weaknesses (1)

- CRT Projectors
  - Projectors not very bright
  - Shock, vibration & heat, hard to keep focus
  - Geometric distortion at wall interfaces
- Tracking
  - One user tracked, distorted stereo for users not at viewpoint
- User Interface
  - Usually 3-D extension of desktop metaphor

CAVE Weaknesses (2)

- Expensive
  - ~$1,000,000 fully outfitted
  - ~$600,000 SGI computers
  - ~$30,000 per projector

Motivation

- Installed MATLAB 5 on SGI Onyx and Pentium
  - Benchmarks on 200 megahertz Pentium Pro ($3000) and 200 megahertz SGI Onyx ($120,000) similar
- Liquid Crystal Projectors sharp, bright, and stable under shock, vibration and temperature variation
- Stereographics Crystal Eyes technology available for Windows NT

MiniCAVE Concept

- Windows NT/Intel Pentium II 466 mhz
- LCD-based projection systems
- 12 ft cubes scaled to 6 ft cubes
- Tracking optional, reduced latency
- Voice command metaphor
- ~$100,000 entry level

MiniCAVE Appearance

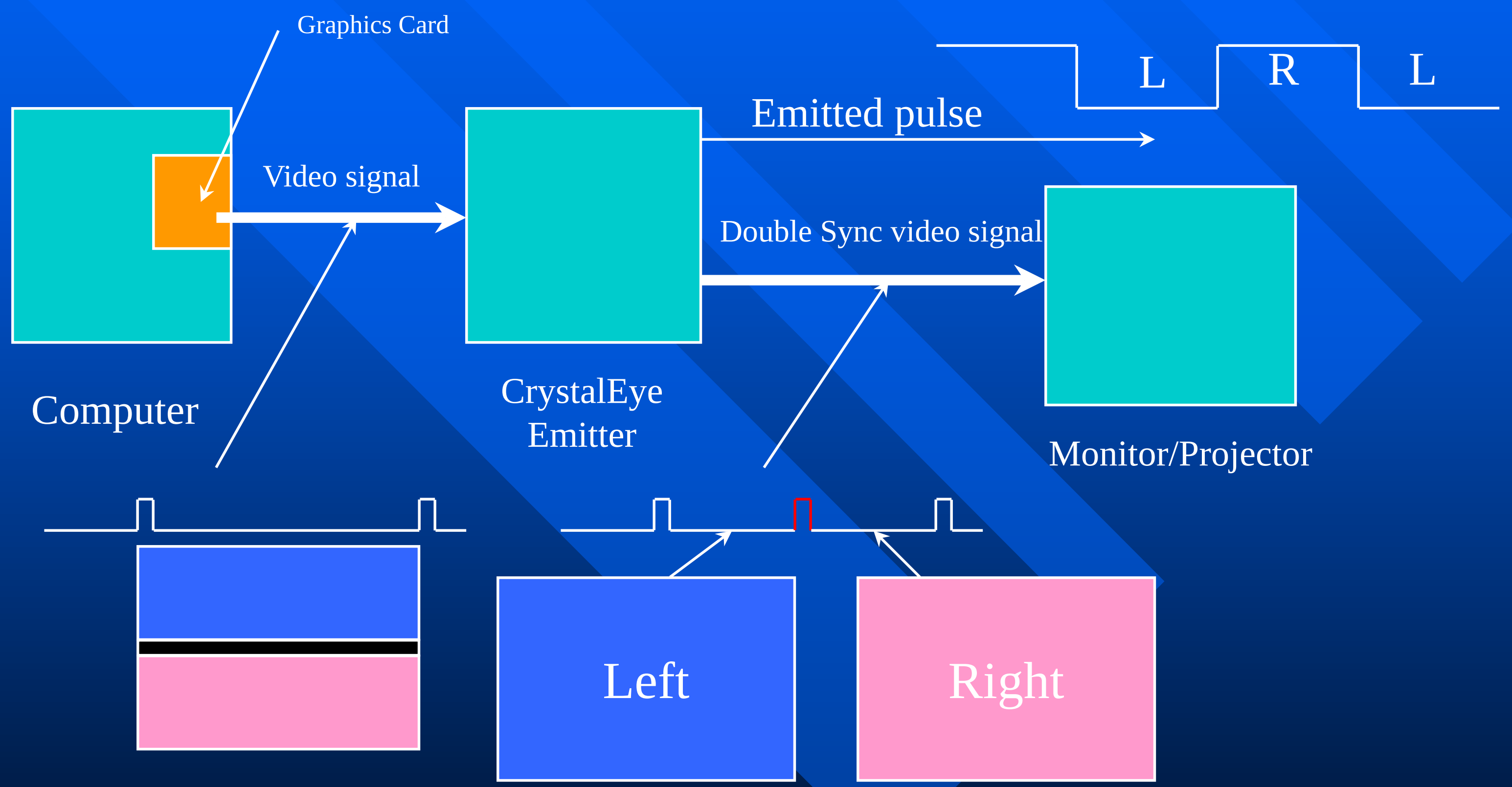
VR from Workstation to PC

- Project Purpose
  - Can the NT workstation really match the SGI workstation in 3D graphics area?
  - Possibility of VR implementation in PC environment, especially MiniCAVE
  - Explore the hardware and software capacities of PC for VR application

- Initial Approach
  1. Porting one SGI GL application, SkyFly, to OpenGL, which is a platform-independent 3D API.
  2. Porting this application to NT environment.
  3. Performance comparison between SGI and NT.
  4. Stereo display on PC using CrystalEyes.
  5. Controlled by voice command.

- Stereo using CrystalEyes
  - Above-below stereo
  - Image resolution 1024x384 each eye
  - Vertical refresh rate 120-150 (60-75 each eye)
    - » SGI monitor can handle both 120 and 150
    - » CRT projector can only handle 120 refresh rate

Principles of above-below CrystalEyes stereo



Speech Motivation

- User Interfaces (Van Dam)
- Shortcuts in XGobi
- User Controls in the C2 Stats Application

Speech Recognition Products

Dragon Dictate

IBM ViaVoice

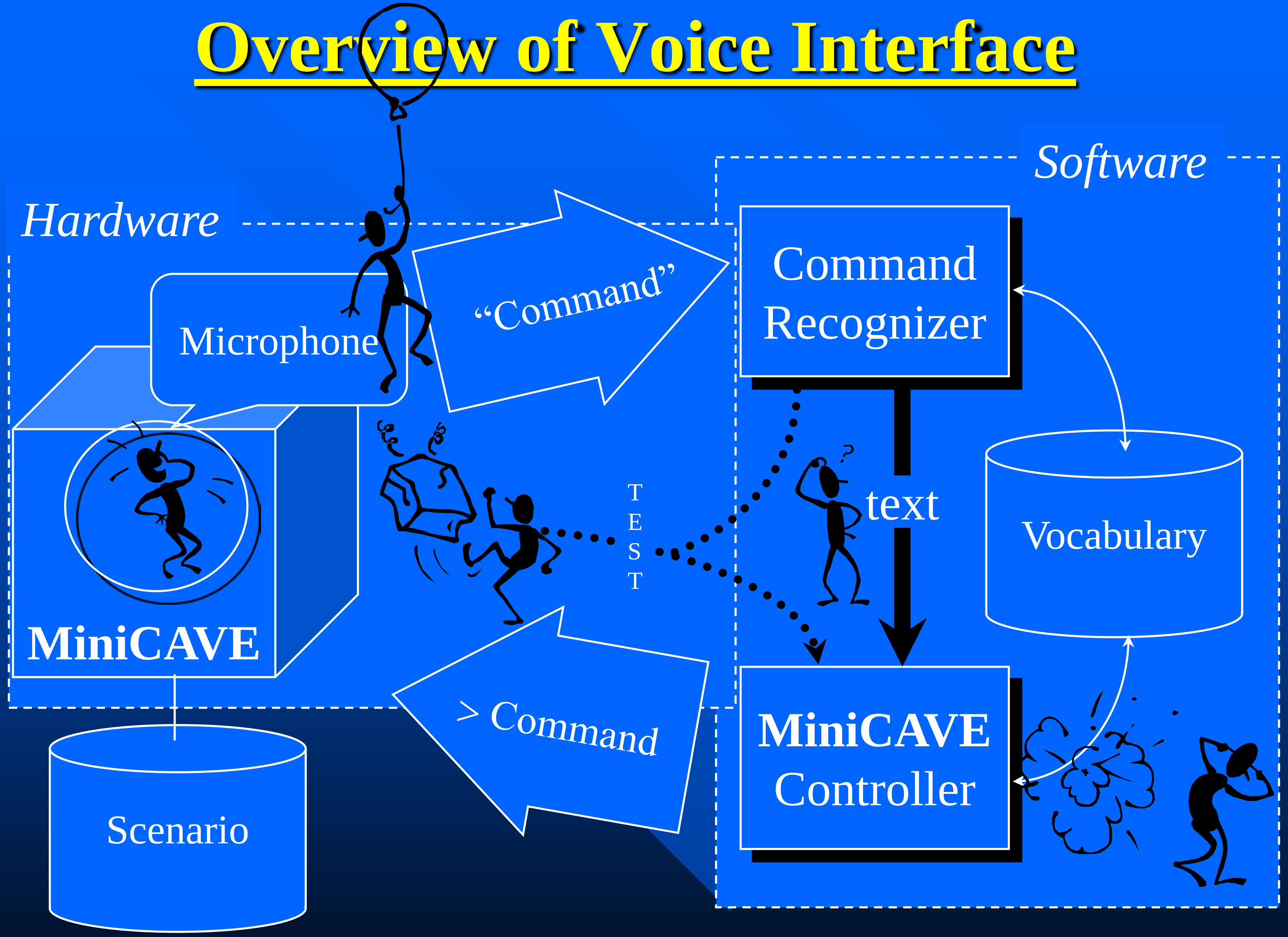
Speech Recognition Technology: Evaluation

1. Can you train the software to understand additional words?
2. Is the software speaker dependent or speaker independent?
3. Can you store different pronunciations of one word into the same database so a spoken word is compared with different pronunciations?
4. How good is performance (i.e., percentage of correctly identified words before and after training)?
5. Does accuracy depend on speaker / accent / training?
6. What improves accuracy relative to the various sources of imprecision?
7. How long does it take to reach various levels of performance?
8. What if we aren’t able to train? What should we expect?

- What’s the good format for voice-controlled navigation in this application? What are the recommendations on the maximum number of words for the application? What do they suggest as maximum number of words in one command? *We currently only have a simple command format: single word, with an around 20 words vocabulary. The generalization appears achievable.*

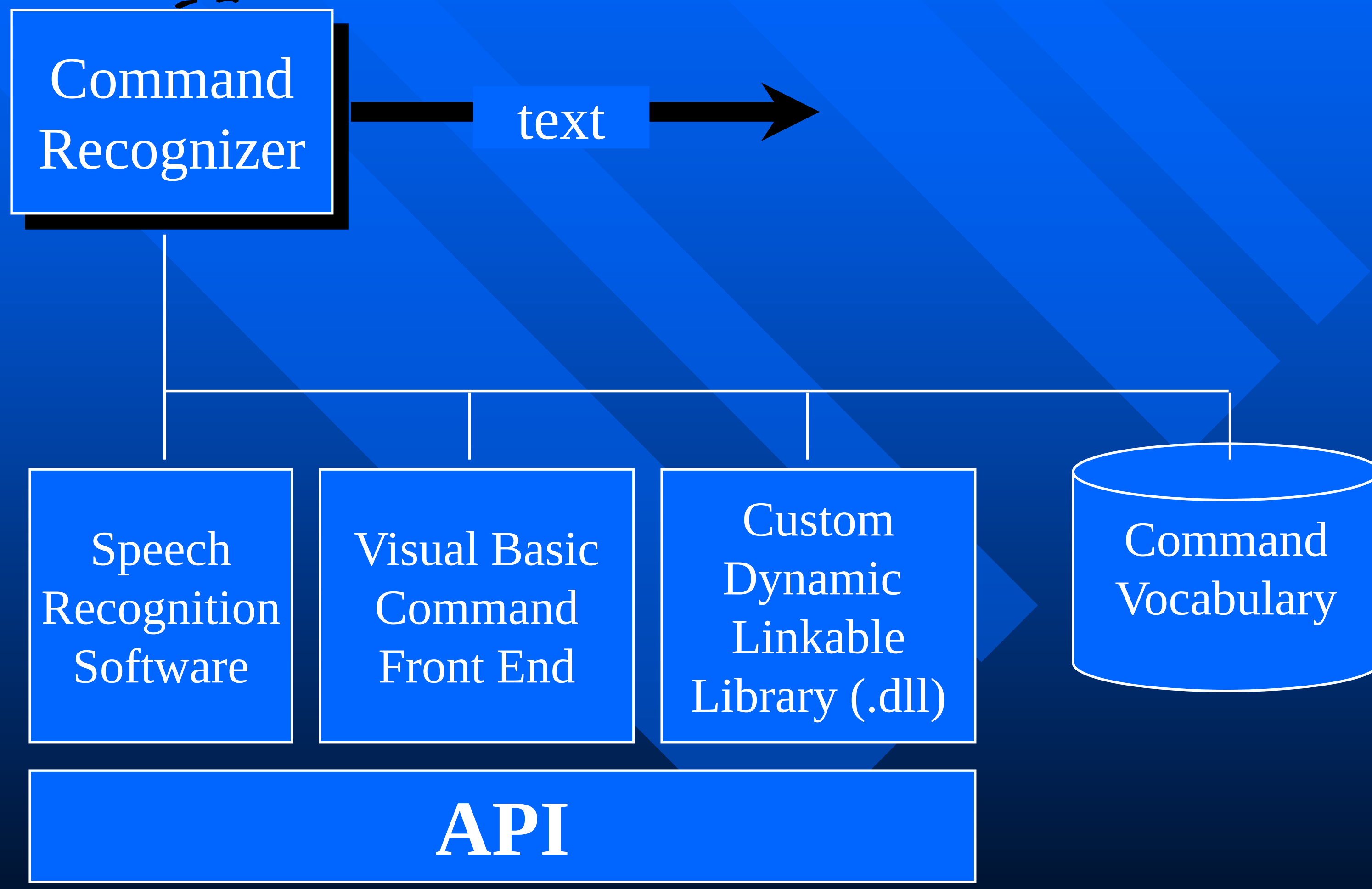
- Voice Control
  - Command Set
    left, right, up, down, fast, slow, forward, reverse, stop, start.
  - Link directly to Dragon Dictate (locally), or link to Custom-DLL (network possible)

Overview of Voice Interface



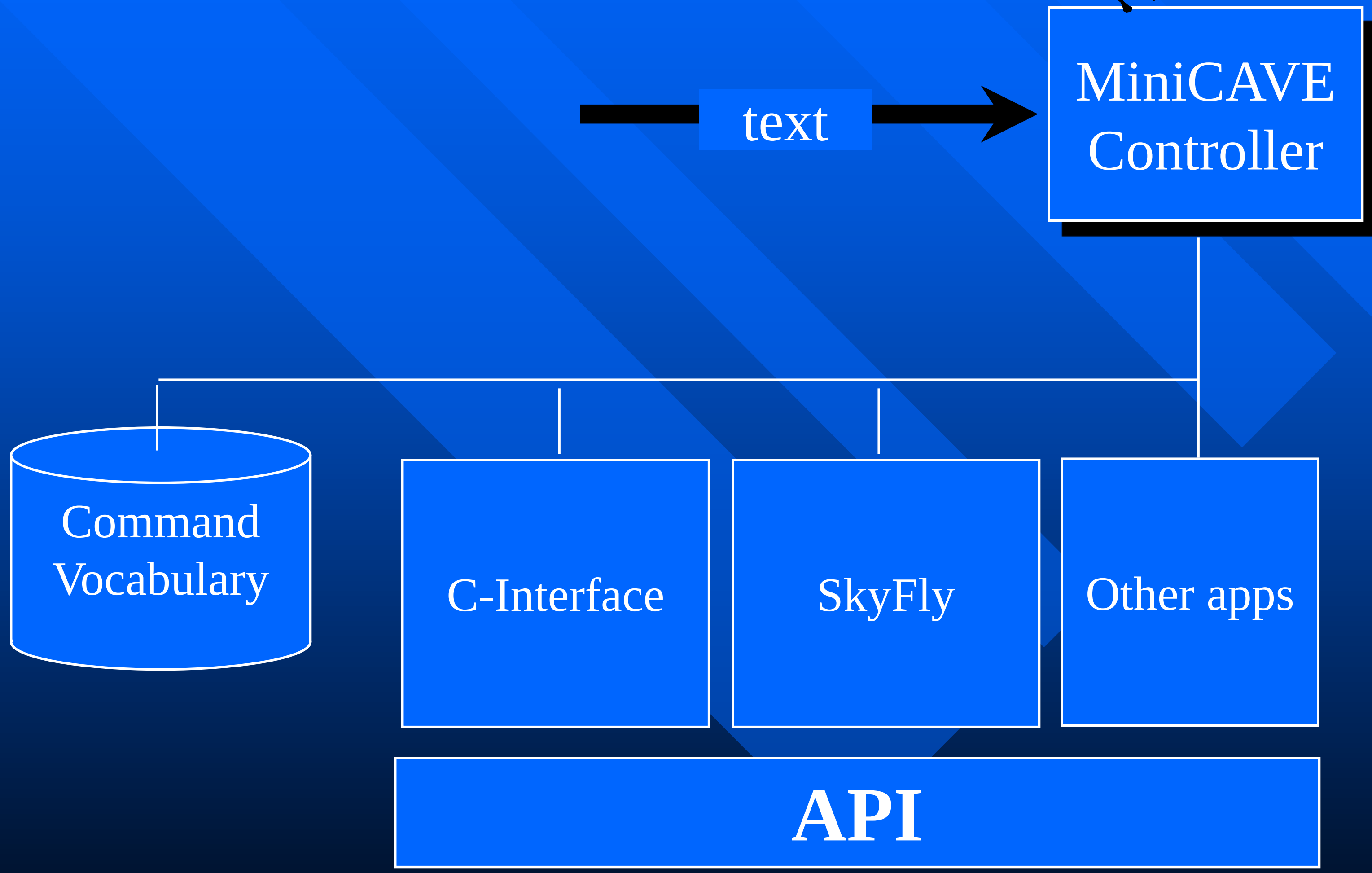
Command Recognizer

Requirement:Capture Voice Command & Output Text



MiniCAVE Controller

Requirement:Capture & Execute Text Command



Approach

- Integrate successfully on one machine, then attempt a multi-machine solution
- Recognition of spoken word causes delay in SkyFly program on 300 mhz Pentium II - much better on 466 mhz Pentium II

Technical Challenges - Successes

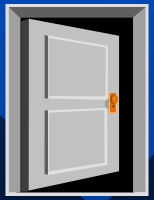
- Port of SkyFly Stereoscopic Demo to NT successful with adequate frame rates on 300 Megahertz Machine
- CrystalEyes interface on NT successful
- Voice Recognition using Dragon Dictate successful
  - But requires Training of Speech Recognizer

Remaining Challenges

- MiniCAVE Libraries
  - Compatibility to Existing CAVE Libraries
- Projection Systems
  - Edge Blending with Digital Projectors
  - Digital Projectors Themselves
    - » Frame Rates
    - » Decay
    - » Image Lock / Stereo Lock

Status (as of 1999)

- Patent Disclosure Filed
- CRADA signed with U.S. Army (White Sands Missile Range) - Awaiting Funding
- Planned EDA/Data Mining Application with Voice Interface
- Major Delay after 300 mhz Machine had been stolen



References

- Wegman, E. J., Symanzik, J., Vandersluis, J. P., Luo, Q., Camelli, F., Dzubay, A., Fu, X., Khumbah, N.-A., Moustafa, R. E. A., Wall, R. L., Zhu, Y. (1999): The MiniCAVE | A Voice-Controlled IPT Environment, In: Bullinger, H.-J., Riedel, O. (Eds.) 3. International Immersive Projection Technology Workshop, 10./11. May 1999, Center of the Fraunhofer Society Stuttgart IZS, Springer, Heidelberg, 179-190.
- Wegman, E. J., Symanzik, J. (2002): Immersive Projection Technology for Visual Data Mining, Journal of Computational and Graphical Statistics, Vol. 11, No. 1, 163-188.

Questions ???

– or –

send e-mail to:

symanzik@math.usu.edu