Perception of Multidimensional Data Presented Through Artistic Techniques: A Qualitative Study

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R. M. Kirby, Department of Applied Mathematics, Brown University

Tuesday, October 3, 2000

Abstract

The authors propose a user study of the usefulness or communicative accuracy of "painterly" techniques for conveying complex data. Painterly techniques allow multidimensional data to be transformed into a two dimensional graphical representation using concepts derived from the study of art and perception.

Participants

PI: J. M. Tasman, Department of Computer Science, Brown University
Co- PI: R. M. Kirby, Graduate Student, Department of Applied Mathematics, Brown University

Consultants

David Laidlaw, Department of Computer Science, Brown University
Cullen Jackson, Department of Psychology, Brown University

Problem

Conveying several values of data through a two-dimensional representation is not an intuitive problem. This type of data is commonly referred to as multivalued, multivariate, or multidimensional data. In the last decade, several methods and techniques have evolved to address this project. A novel technique, developed by David Laidlaw, is termed “painterly” visualization. This method uses a collection of ideas from both art and cognitive science. Different values can be conveyed through modification of visual parameters, or “modalities.” While this technique seems to hold great promise and has been successfully applied to several problems such as MRI and fluid flow data, a perceptual evaluation of the value of this method has not been undertaken. We therefore propose to perform a user study as an initial investigation into the value and intuitive perceptions of the painterly visualization technique. We refer to a “dimension” or “modality” in image as the visual features which can be controlled to convey one dimension of data. Some of the questions to be addressed include:

*are some modalities more effective than others?

*are patterns incorrectly perceived when nothing is there?

*is there interaction between modalities- do some re-enforce or cancel each other out?

*what is the affect of academic, artistic and scientific background on interpretation of these images?

Over a six week period, the authors will query a group of subjects from a variety of backgrounds, and record their responses to a series of images produced with these painterly techniques.

Background

Serious investigation of visualization of multivalued data began in the early 1990’s. As computer power and availability grew, more large datasets could be generated, often at a quicker rate than they could be interpreted. Both experiments, simulations, and analyses accumulate piles of data which may never be fully appreciated, as interpretation requires the experience, judgment, and context that only a human observer can provide. At the same time, computer graphic displays became inexpensive and prolific. Researchers soon realized that to make use of this display capability, a method of conveying these large quantities of numbers in a meaningful way must be developed.

Brain Science

The brain and its visual perception system have evolved over millions of years to provide us with the ability to create a model of reality which allows us to survive: our distant relatives who couldn’t see the branch in the leaves, or didn’t see the bent tops of grass on the plain, didn’t make it. Today, over half of the structures in the human brain are directly involved in visual processing. It is only in the last century that we have begun to appreciate the neural basis for reality.

Cognitive, perceptual, and neurological studies have elucidated some of the most basic structure and levels of visual system. Beginning in the retina, neural networks perform edge and motion enhancement. ”Maps” in the cortex contain arrays of cells which respond to basic properties such as color contrasts and line orientation. In this way, we “see” not the “objective reality,” but a model filtered through our specific circuitry.

Art

How do we make use of this exquisite hardware? While neural levels of understanding are new, cognitive scientists have not been the only ones to investigate and model the way our specific, human eye and brain see the world. For thousands of years, artists have been building an empirical library of complex and subtle techniques which can be used to convey a human sense of meaning.

An interesting phenomenon arose as “objective”, realistic techniques such as daguerreotypes and photographs were developed in the 1800’s. A school of painters who came be known as Impressionists turned away from the goal of capturing the world in a purely directly way. Instead, they turned their attention to more abstract methods for conveying rich, personal meaning: composition of objects and scenes was no longer the only way to get beyond the mechanics of depiction. The experimental styles of Monet, Van Gogh, and others explored the ways in which the physical media of oil, brush, and canvas could, perhaps by an intuitive understanding of the human ”eye”, jump beyond the goal of one-to-one relationships between form and meaning. In other words, this can be seen as a graphical exploration of multidimensional communication.

Computer science results

Many people have explored the question of multidimensional display ([Inselberg 1994], [Rogowitz 1994], [May 1999]), but a few people who have applied insight from human perception and actually performed user studies are worth reviewing.

Healey [Healey 1993, 1995] began by explicitly using “preattentive”, automatically parsed visual features such as “color, orientation, intensity, size, shape, curvature, and line length.” Using two of these features, he ran experiments which demonstrated that they did not interact or interfere with each other. He went on to test an application of these methods on real data sets [Healey1, 1998]. He created texture patterns from these principles [Healey2, 1998] which were again applied to real world problems. His latest work [Healey 1999] is in automatic determination of appropriate visualization techniques, again using these principles. [Joslyn 1995] also uses results from human perception to derive improved and novel glyphs.

Laidlaw and Kirby have been on the forefront of looking to the artistic world for inspiration in conveying scientific data. Rich, layered textures can be built up with such primitives as triangles, ellipsoids, and shading. The painterly technique is well described in [Kirby 1999] and [Laidlaw1 1998]. This method was successfully applied in several fields ([Kirby 1999], [Ahrens 1998], [Laidlaw2, 1998]. However, there has been no investigation into the effectiveness of these techniques.

Hypothesis

Several questions will be addressed:

*patterns are not incorrectly perceived from random noise. While the eye looks for patterns, we propose that the more modalities are randomized and not reinforcing each other, the more the data will actually appear random.

*certain communication modalities are easier to see than others. Conversely, related data in similar modalities will be easier to see (see above and below.)

*there is interaction between higher-level modalities, such as texture and opacity of an ellipsiod. [Healey 1993, 1995] showed that for two preattentive features, there was no interaction. Some features to be investigated use higher level neuronal features, such as textures. Many inputs may be harder to separate in this case.

*Different academic, experiential, scientific, and artistic backgrounds will affect interpretation of these images. We hypothesis that of art students, computer graphics specialists, physicists, and biomedical researchers, art students would be most keen on picking up subtle differences between images, as their eyes are probably most trained for detail.

Methodology

Creation of Sample Images

Subjects will view a series of artificial datasets rendered with the painterly methods. Datasets will be created using mathematical software available on department machines (such as MatLab), and processed with the custom AVS rendering system, also available on department machines. Images will be presented using a computer display, on a department machine either in the Sun Lab or a more private situation if it can obtained.

We refer to a "dimension" or "modality" in the dataset or image as the visual features which can be controlled to convey one dimension of data. Several series of images will be created:

*purely random images will be used to investigate possible mis-perception where nothing exists in the data.

*images with one dimension varying against all other dimensions uniformly randomized will investigate effectiveness of each modality. Datasets will be created mathematically, with such features as gradients, Gaussian distributions, and geometrical shapes such as circles and spirals.

*combinations of dimensions varied together will investigate interference effects across visual features.

Evaluation

There are no clear results on what makes a "good" visualization. [Georges 1995, 1998] discusses the unresolved challenges of in multidimensional visualization, including evaluation. [Rushmeier 1995] discusses the lack of work done to determine definitions or evaluation practices. [Rushmeier 1997] revisits these questions with another survey, but no definite answers are determined. The question is brought up if general methods and descriptions for evaluation are possible, or "whether all visualization is case specific." We address an aspect of this question by asking subjects to rate their artistic ability, and provide biographical and educational background information. We will provide questions with a scale of 1-7 to rate basic characteristics of the image, along with space for descriptive comments.

Sample question:

Do you see motion in the image?
If so, how strongly? 1 2 3 4 5 6 7
In what direction(s) (draw arrow):

Summary

We will investigate several questions relating to the interpretation and effectiveness of multivalued dataset visualized with David Laidlaw's "painterly" techniques. Questions of effectiveness of each visual feature or modality, interaction between visual elements, and affect of background on perception will all be addressed. In a relatively short time frame, we believe that we can make a solid initial evaluation of a novel and successful techniques, with an analysis of empirical effectiveness.

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Schedule

Week 1- milestones reached: Begin recruitment of subjects. Determine stimulus and metrics to be used.

Week 2- milestones reached: Create stimulus in AVS system.

Week 3- milestones reached: Begin running subjects.

Week 4- milestones reached: Continue running subjects.

Week 5- milestones reached: Begin data analysis.

Week 6- milestones reached: Complete data analysis. Prepare abstract and final presentation.

CV for J. M. Tasman

Personal

Name: Joshua M. Tasman
Email: jmt@cs.brown.edu

Education

Brown University, Bachelor of Art Degree in Computer Science, Expected December 2000.

Employment

Kewalo Basin Marine Mammal Laboratory, University of Hawai'i at Manona May 2000 - August 2000: Research Assistant / Computer Programmer

Project Phoenix, SETI Institute September 1999 - December 1999: Computer Programmer / Research Assistant
Configuration Choices for the Allen Telescope Array D.C.-J. Bock, M.C.H. Wright, W.J. Welch and J. Tasman, poster presented at the workshop "Technology Pathways to the Square Kilometre Array", Jodrell Bank Observatory, UK, August 2000.

Visual Perception Lab, Brown University Department of Cognitive Science January 1998 - May 1998: Research Assistant

Human Neurophysiology Lab, University of Louisville Medical School, June 1993 - August 1993, June 1994 - August 1994: Computer Programmer / Research Assistant

Related Skills and Experience

As an undergradate, I have developed my programming skills both in the academic and research environments. I have studied computer graphics and software engineering in the classroom, and have experience working with complex, real-world data sets such as dolphin echolocation acoustics, radio telescope array configuration simulations, and human EEG signals.

CV for R.M. Kirby

Personal

Name: Robert M. Kirby II
E-Mail: kirby@cfm.brown.edu

Education

Brown University, Ph.D candidate in Applied Mathematics, Expected May 2002.
Advisor: George Em. Karniadakis, Professor of Applied Mathematics, Brown University

Brown University, Master of Science Degree candidate in Computer Science, Expected May 2001.
Advisor: Andries van Dam, Professor of Computer Science, Brown University

Brown University, Master of Science Degree in Applied Mathematics, May 1999.

The Florida State University, Bachelor of Science Degree; Major(s): Applied Mathematics and Computer and Information Sciences; Graduated *Summa Cum Laude*

Employment

Division of Applied Mathematics and Department of Computer Science, Brown University
September 1997 - present: Graduate Student

The Geophysical Fluid Dynamics Institute at Florida State University April 1997 - August 1997: Systems Manager

The Geophysical Fluid Dynamics Institute at Florida State University June 1992 - April 1997: Computer Programmer/ Research Assistant

Related Work

During my graduate studies, I have participated in many fluid flow visualization projects which have led to publishing results on the use of both painterly techniques for two dimensional fluid flows and immersive virtual reality techniques for visualizing three dimensional fluid flows. Current work involves attempting to quantify through user-studies the quality of visualization methodologies.

From dhl@cs.brown.edu Mon Oct 2 18:15:50 2000
Date: Mon, 02 Oct 2000 17:56:17 -0400
From: David Laidlaw dhl@cs.brown.edu
To: Joshua Tasman jmt@cs.brown.edu
Subject: Re: 237 / support

Josh -

I am looking forward to participating in your proposed CS237 project to explore textures for scientific visualization.

-David

From cullen@mailserver.cog.brown.edu Mon Oct 2 16:42:43 2000
Date: Mon, 2 Oct 2000 16:33:36 -0400 (EDT)
From: Cullen D. Jackson cullen@mailserver.cog.brown.edu
To: Josh Tasman jmt@cs.brown.edu
Subject: Support

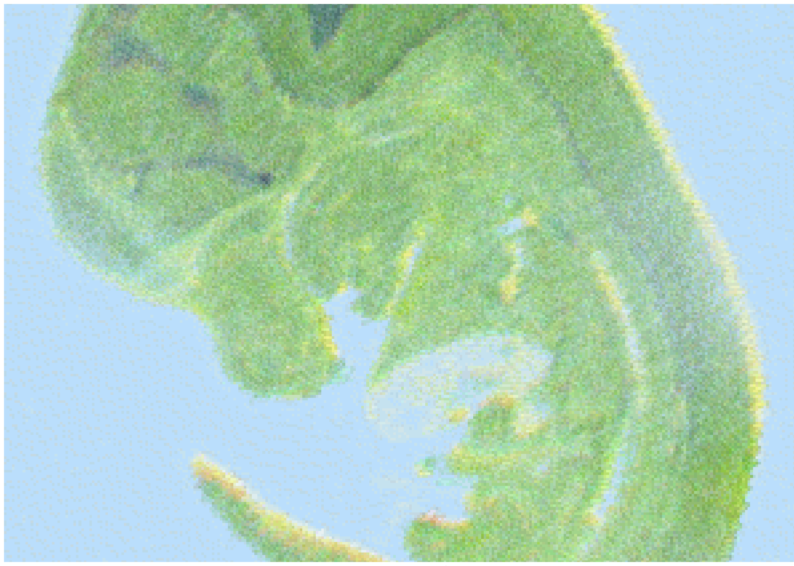
To Whom It May Concern,

I am happy to support Josh Tasman in his project for Prof. Laidlaw's visualization class. Josh has asked me to provide expertise and information on running human behavioral studies.

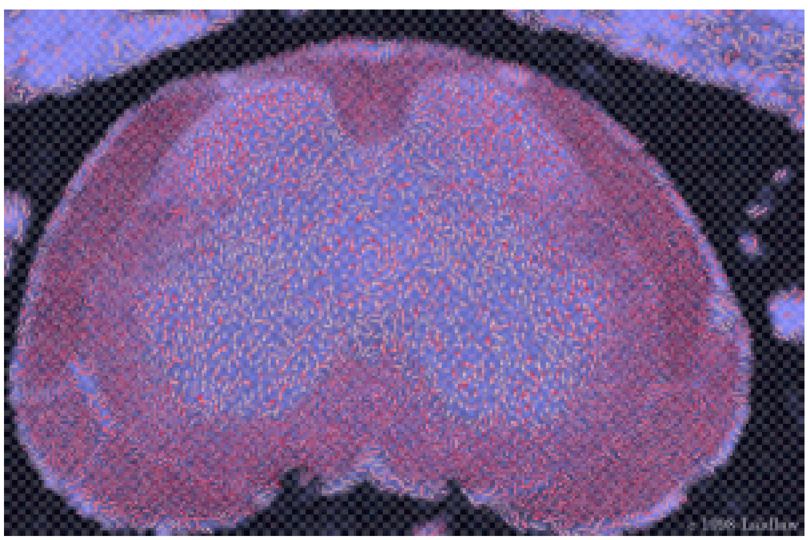
Sincerely,

Cullen Jackson

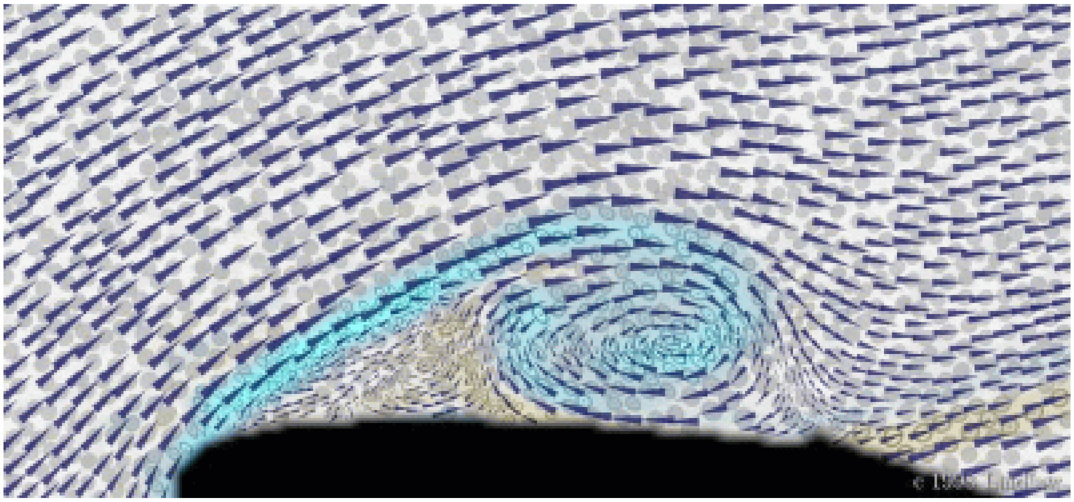
Examples of Multivaled Visualization Using Painterly Techniques



6-valued MRI image of a mouse embryo



7-valued MRI image of a mouse spinal cord



6 Valued fluid flow simulation visualization

Data Visualization for a Teaching Radio Telescope

M.L. Lichtman
(PI)
Department of Engineering
Brown University

G.S. Tucker, Ph.D.
(Collaborator)
Department of Physics
Brown University

Abstract: This project will create visualization software for hydrogen vector data obtained by a student built and operated radio telescope. The software should facilitate the understanding of the data for first-time students in astronomy. Previous radio astronomy projects produced charts of raw data that are difficult for a student to understand.

1. Motivation

A radio telescope has been built at Brown University for the purpose of undergraduate laboratory use. The students using this telescope will be first-time astronomers, and as such should not be expected to construct images in their minds from near-raw data. In fact, as radio waves are a type of light wave, it only makes sense to create a graphical visualization for the data. However, two previous undergraduate projects such as this (Berkeley 1995 and Calgary 1996) have made wonderful radio observations with their undergraduate radio telescopes, only to leave the data in a fairly inaccessible form. The radio telescope at Brown University will be utilized by astronomy students who will not be expected to understand the intricacies of the observation data, but who will be capable of learning much from a well formed visualization of the data.

2. Problem

Data collected from the radio telescope will be in the form of intensity data around 1.42 GHz, with a 200 kHz bandwidth. This will show the density of hydrogen at the observed point, plus through Fourier transform techniques, give us radial velocity data as well. All of the signal isolation and amplification is done in hardware, however, the Fourier transforms are done in software on a PC, hence the data is already in a readily usable form. The difficult aspect of the problem is to create visualization software for a flat screen which will be an accurate reflection of the spherical sky. Ease of understanding is the primary concern here.

3. Development

1. The first goal necessary is to standardize the data format that will be used so that we can continue with developing the visualization software with an unambiguous understanding of what data we have and what can be done with it. Included in this phase of development is to decide what the salient features of the data collected are. If we wish to make the data easy for undergraduates to understand, we must decide what exactly we wish for the students to get from it; thereby producing an uncluttered, straightforward visualization.

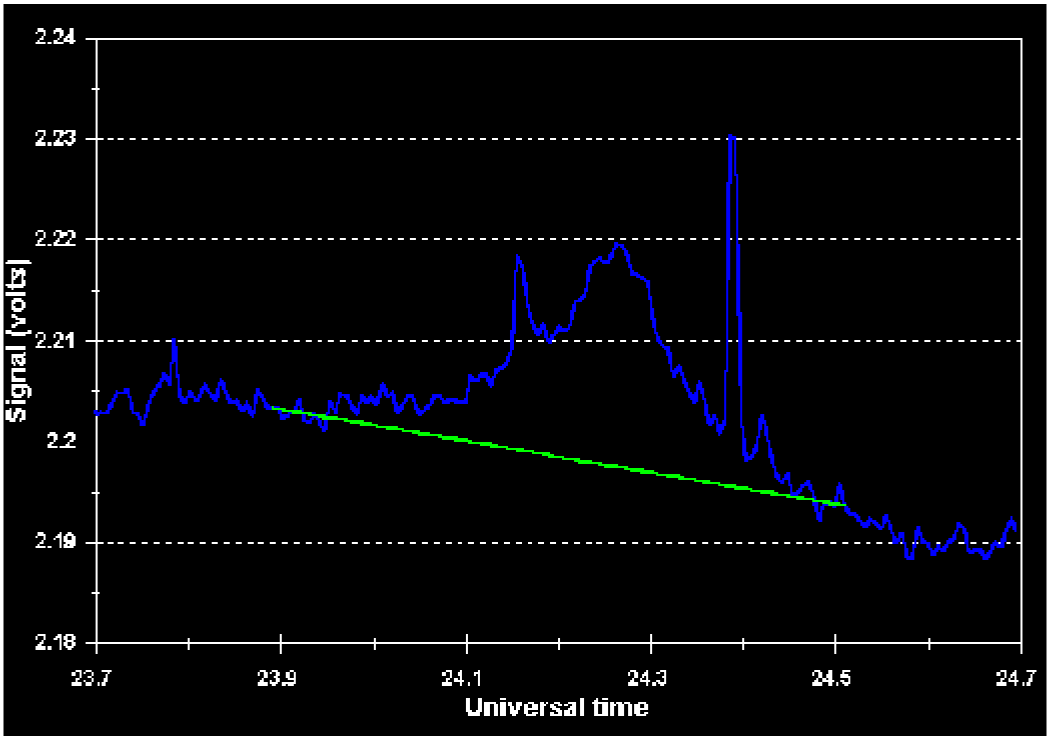
2. The bulk of the project will be to create the visualization software. As this is expected to be the most difficult task, it will also be allotted the most time.

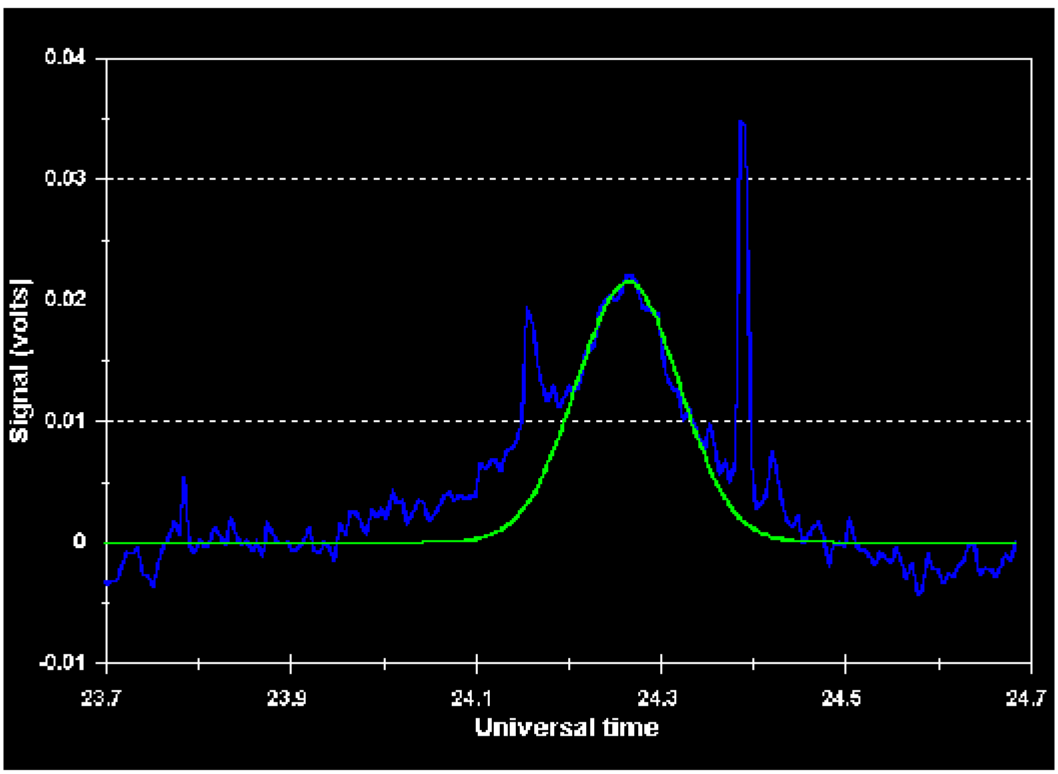
3. One the preliminary software has been written, a focus group of beginning astronomy students will be collected to evaluate the software, and it will be revised, based on their criticism.

4. Upon completion of the software, a paper will be written reporting the results of the project; its success and what decisions were made concerning the best way to visualize the radio data for beginning students.

4. State of the Art

Both U.C. Berkeley and U. Calgary have built undergraduate radio telescopes. However, their projects were useful mostly only to the students who built the devices. The Brown Physics Department intends to use its radio telescope for lab purposes. The following pictures are examples of final data from the U. Calgary telescope. It is clear why they would be unacceptable for teaching purposes:





4. Significance

The importance of this project for the field of radio astronomy will be quite noticeable.

Few universities include radio astronomy laboratory work as part of their undergraduate astronomy courses. The reasons for this include lack of equipment, and inaccessibility of the data for those universities that do have the equipment. If a successful program can be developed here at Brown, it will pave the way for other universities, thereby improving the state of radio astronomy education nationwide.

The computer science aspect of this project is also rather significant. Although new techniques will doubtfully be used, the application of real time display of radio astronomy data for teaching purposes is a novel one, and certain to be insightful.

5. Schedule

Week 1:	Data Standardization
Week 2-3:	Software Development
Week 4:	Software Evaluation
Week 5:	Software Refinement
Week 6:	Paper Writing

References

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Nelson, Lee J.
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Advanced Imaging 15 3 2000 Cygnus Publ Inc 2 pp 1042-0711

Refling, John P.; Pennypacker, Carl R.
Hands-on universe: bringing astronomical explorations to the classroom
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Song, Deyang; Norman, Michael L.
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U.C. Berkeley

Berkeley Undergraduate Radio Astronomy Observatory
http://www.ugastro.berkeley.edu/radiolab/index.html 1995

U. Calgary

Radio Telescope Handbook
http://www.ras.ucalgary.ca/radiotel/index.html 1996

C.V. for M.T. Lichtman

- Undergradutate senior at Brown University, majoring in Aerospace Engineering.
- Head undergraduate astronomy TA at Brown University.
- Undergraduate project leader in a GISP which designed and built a 1-m Hydrogen-line spectrometer radio telescope in the Spring 2000.

C.V. for G.S. Tucker

RESEARCH INTERESTS:

- Measurements of the cosmic microwave background, development of x-ray detectors for astrophysics.

VITA:

- Professor Tucker joined the Brown Department of Physics in 1997. He has done postdoctoral work at the University of British Columbia and at the Harvard-Smithsonian Center for Astrophysics. The primary emphasis of his research has been measurements of the cosmic microwave background from the ground, high altitude balloons and from space. The main goal of this research is to determine how structure formed in the universe and to determine the values of the key parameters of cosmology.

RECENT PUBLICATIONS:

- "A Search for Small-Scale Anisotropy in the Cosmic Microwave Background", (with G.S. Griffin, H.T. Nguyen, and J.B. Peterson), Ap. J. 419, L45 (1993).

- "Cryogenic Bolometric Radiometer and Telescope", (with J.B. Peterson, C.B. Netterfield, G.S. Griffin, and E.L. Griffith), Rev. Sci. Instr. 65, 301 (1994).

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Art and Perception:
Visualizing Arnheim's Visual Tension Theory

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David H. Laidlaw
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Abstract

We will identify a set of devices used in human visual perception, and superimpose them on a 2D image as force fields using texture mapping. From here, these fields can be modified to examine the artistic intentions in terms of organization and order. The approach will be interdisciplinary, drawing from the fields of psychology, cognitive science, computer graphics, computer vision, and visual art theory.

1. Introduction

Professor Rudolf Arnheim, author of the landmark, “Art and Visual Perception: A Psychology of the Creative Eye,” contends that there is a set of perceptual laws which all humans naturally apply when viewing visual media. These laws, referred to by Arnheim as psychological forces, are treated by artists in order to convey balance, form and meaning to an audience. We will identify a set of these forces, and display them graphically. From here, these forces, or tensions, can be modified to examine what an artist was intending in terms of organization and order. Drawing from the fields of psychology, cognitive science, computer graphics, and visual art theory, we intend on creating a concrete representation of these abstract psychological forces.

Psychological forces, as defined by Arnheim and his collegues, are the net interplay of directed tensions recorded when a person forms a percept. This goes beyond perception as just an arrangement of objects, colors, shapes, movements, and sizes. A simple example provided by Arnheim is the tension perceived when a symmetrical object, such as a sphere, is positioned within a square just slightly off center (Fig. 1, p. 10 [1]). The resulting tension is a pull of the sphere towards the center of the scene, or the attraction towards a boundary. In addition to boundary attraction, Arnheim introduces the concept of a *structural skeleton*, the framework of a given image when shows the role of each pictorial element in terms of overall balance. While the structural skeleton of an object is related to its underlying shape, it rarely coincides with it; rather, the resulting skeleton is a representation of the simplest structure obtainable from the given shape. For example, different triangles have distinct visual character which can only be inferred from the structural skeleton, not the shape itself (Fig 2, pp. 93-94 [1]).

Balance is another key factor in the perception of an image. Arnheim refers to the center and corners of an image as “magnets of unequal power.” He states that the corners of an image tend to have less pull than the center. Moreover, there is a general tendency for psychological systems to change in the direction of least tension. He continues to state that the percept is a continuous landscape in which the lines of the structural skeleton slope off in both directions. There is no point free from these forces, only “restful” states at points of balance.

There are a number of distinct psychological forces that generate visual weight: depth, position, size, color, intrinsic interest, isolation, simplicity, orientation, and knowledge of an object’s actual weight. These are the forces that we will visualize through this research.

1.1 Specific Goals of Project

This study will provide an interactive software application that will be able to parse simple 2D images, and produce a visual representation of the active perceptual forces inherent to the image. From this, it is postulated that one will be able to gain a clearer understanding of the structural intentions of the artist. This would be useful to visual art theorists, perceptual psychologists, as well as to computer scientists in the fields of computer vision and artificial intelligence. A secondary goal of this project is to generate novel research projects building from this framework. This could materialize in several forms such as educational software development, as well as novel computer vision techniques. This will be examined more closely as the project is executed.

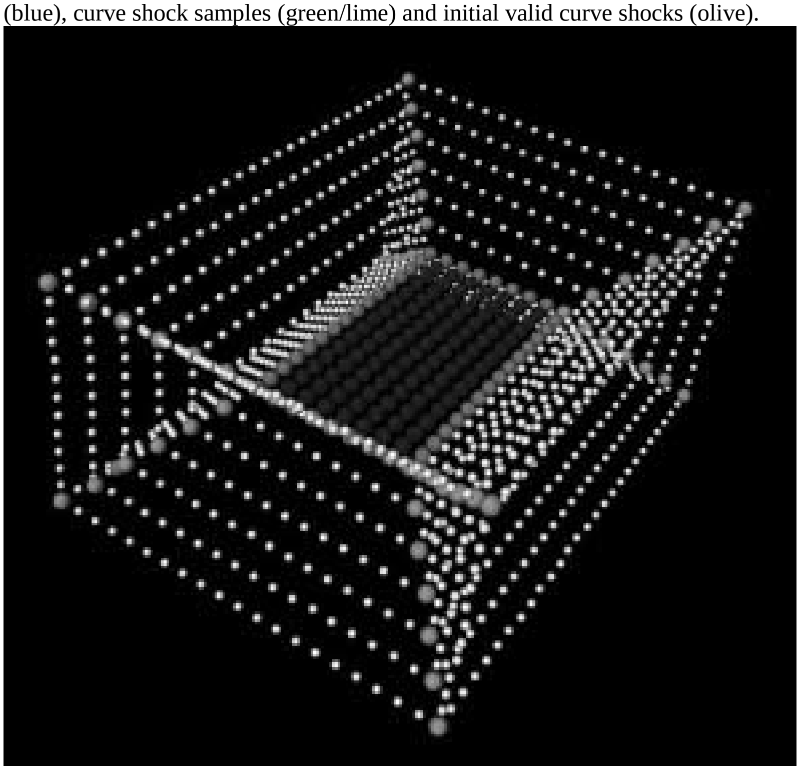
1.2 Significance

This research is relevant to current advances in perceptual psychology, and artificial intellegence in several ways. Visual perception research is currently making widespread advances. Methods of directly observing the brain and the use of resulting data in contexts borrowed from experimental psychology, are providing researchers with new perspective. The overall architecture of the visual system is believed to be understood, primarily as a result of interdisciplinary work in computational vision, biology, physiology, and psychology.

1.3 Related Work

While much of the research in this area has been studied extensively in the past 30 years, this work remains novel in the development of a computer application to visualize these theoretical concepts. The field of perceptual psychology has made significant advances over the past 30 years, a great deal of which has focused in the algorithmic representation of visual perception. Professor Frederic Leymarie has developed algorithms for obtaining the structural skeleton of a given image, and has applied this to some of his current research, such as the sub-voxel tracing of medial sheets and curves (Fig 3). Using this successful application of a 3D structural skeleton, we will develop an initial 2D instance to apply to our images.

Figure 1. Subvoxel loci of sheet shock samples (white), initial valid sheet shocks (blue), curve shock samples (green/lime) and initial valid curve shocks (olive).



2. Research Plan

In addition to a weekly meeting between at least two of the researchers, and regular email dialogue between all participants, the following will occur:

Week 1: Literature review; high-level software design; work delegation
Week 2: Integration of existing structural skeleton data; brainstorming of visualization techniques; meeting with Prof. Laidlaw to review visualization ideas
Week 3: Consolidation of visualization techniques; coding of visualization
Week 4: Continue visualization development
Week 5: Brainstorm on research topics stemming from this project; complete visualization development
Week 6: Presentation preparation; final abstract writing

3. Summary

We will identify a set of visual psychological forces, as defined by Rudolph Arnheim, and display them graphically. From here, these tensions will be modified to examine the intentions of the artist in terms of organization and order. This research is relevant to current advances in perceptual psychology, and artificial intellegence. Drawing from the fields of psychology, cognitive science, computer graphics, and visual art theory, we intend on creating a concrete representation of these abstract perceptual forces.

Researcher

James S. Davidson
Computer Science

Skills

Computer programming (C++, Java), object-oriented design, medium-scale software design and project management, grant proposal experience in the field of ecology

Researcher

Josh M. Tasman
Computer Science

Skills

Relevant classes taken (calculus, linear algebra, numerical methods, signal processing, ode's, pde's, etc.): calc III and linear algebra, computer graphics, software system design, intro to neuroscience, several cognitive science courses.

Date: Tue, 3 Oct 2000 10:36:51 -0400 (EDT)
From: Joshua Tasman <jmt@cs.brown.edu>
To: James Scott Davidson <jsdavids@cs.brown.edu>
Subject: Re: Collaboration Request

To Whom it May Concern-

I would be happy to work with Scott Davidson on his project "Art and Perception: Visualizing Arnheim’s Visual Tension Theory."

-Josh Tasman

Consultant

Frederic Leymarie
Graduate Student, Engineering, Computer Vision and Graphics

Skills

-PhD. Candidate in computer vision and graphics
-prior research, and extensive knowledge on computer vision and perceptual psychology
-project manager in enterprises pertaining to one or more of the following domains:

creation, design & implementation of multimedia applications, e.g. in the domains of video games, cinema
post-production & special effects, virtual fashion show, ...
communication systems, using video and still imagery,
modeling and simulation of physical phenomena,
combined image analysis and synthesis (e.g. for the creation of virtual cities),
creation and handling of 3D multimedia objects and databases,
Geographic Information Systems,
Architectural and Archaeological Information Systems,
Medical Information Systems,
Environmental Emergency Systems.

Date: Tue, 03 Oct 2000 10:49:38 -0400
From: Frederic Leymarie <leymarie@lems25.lems.brown.edu>
To: James Scott Davidson <jsdavids@cs.brown.edu>
Cc: David Laidlaw <dhl@cs.brown.edu>, Joshua Tasman <jmt@cs.brown.edu>
Subject: Re: Collaboration Request

Good morning,

yes, count me in.
I will bring computational vision expertise and general knowledge and
interest
in all
the other mentioned areas.

Frederic
--
Frederic FOL LEYMARIE, R&D Project leader, SHAPE Lab.
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---
It does play with dice ... but are they fixed?

Consultant
David Laidlaw
Professor, Computer Science

Skills

-Ph.D., Computer Science, California Institute of Technology, 1995.
Geometric Model Extraction from Magnetic Resonance Volume Data
-an expert in the field of scientific visualization; has carried out extensive interdisciplinary research into robust and effective computer science and visualization tools to solve problems in biology, fluids, medical imaging, archaeology, geology, geography and other disciplines. Collaborative work with colleagues in these areas guides the research and provides a mechanism for evaluating the usefulness and robustness of results.
-has published numerous articles relevant to scientific visualization, and is the recipient of several NSF and NIH grants

Date: Tue, 03 Oct 2000 11:08:44 -0400
From: David Laidlaw <dhl@cs.brown.edu>
To: James Scott Davidson <jsdavids@cs.brown.edu>
Subject: Re: Collaboration Request

Scott -

I would be happy to provide visualization and graphics insight to yur project, "Art and Perception: Visualizing Arnheim's Visual Tension Theory."

-David

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Optimal Vector Placement: Cartesian versus Random: A User-Study

R.M. Kirby (PI)
Division of Applied Mathematics

J. Tasman (Co-PI)
Department of Computer Science

W.H. Warren (Collaborator)
Department of Cognitive and Linguistic Sciences

D.H. Laidlaw (Collaborator)
Department of Computer Science

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Abstract

The goal of this project is to determine if Cartesian placement of vectors is better than a random placement of vectors when trying to identify the number and location of critical points within a field. We visualize sample analytic vector fields using both Cartesian and random distributions and two user-studies are accomplished to quantify results.

1 Motivation

Arguably, one goal of scientific visualization is to represent physical quantities for interpretation without biasing what is inferred from the data by the particular choice of the visualization method. In experimental sciences, great care is taken when determining where data is to be sampled so that incorrect inferences are not made concerning the nature of the data. Must these same types of considerations be made in visualization? Questions of this type have been brought up in the works of Tufte (1983), Cleveland (1985) and more recently Ware (2000). In all three cases, much advise is given from a qualitative, or anecdotal perspective; user-studies pertaining to the questions raised are still very limited in both their number and their scope. It is because of this that we are motivated to provide quantitative answers to these types of questions.

2 Problem Statement

The goal of this project is to attempt to quantify the results of one particular visualization question: If given an analytic function definition of a vector field, which distribution of vector icon placement is optimal for visualization? In this project, we will use classic examples from critical point theory to create sample analytic vector fields. We will then create vector plot visualizations using both Cartesian and using uniform random distributions for the vector icons. Two user-studies will be accomplished with the purpose of determining which distribution allows people to accurately identify the number and location of the critical points within a vector field. The goal of these user-studies is to determine if Cartesian placement of vectors is better than a random placement of vectors when trying to identify the number and location of critical points within a vector field.

This project will combine both concepts from computer science and cognitive science to design and execute two user-studies whose scope is clearly defined, and whose results will be interpretable. Though the particular visualization methods used are not novel (vector visualization), this project has significant visualization merit; *quantitative results from this user-study may lead to better visualizations*. This work is novel in that it attempts to answer a very specific visualization question through the use of a quantitative measuring tool, the user-study.

3 Research Plan

Our research plan consists of two major components: visualization development and user-study development.

3.1 Visualization Development

To eliminate any biases that may exist in experimentally obtained data, we have decided to use classic examples from critical point theory to create sample analytic vector fields for visualization. Figure 1 outlines the six basic critical points that we will use in our visualizations. Visualizations will be created by the evaluation of an analytic function created by the linear combination of functions defining these critical points. For our purposes, visualizations will be created which contain 0,1,2,3 and 4 critical points.

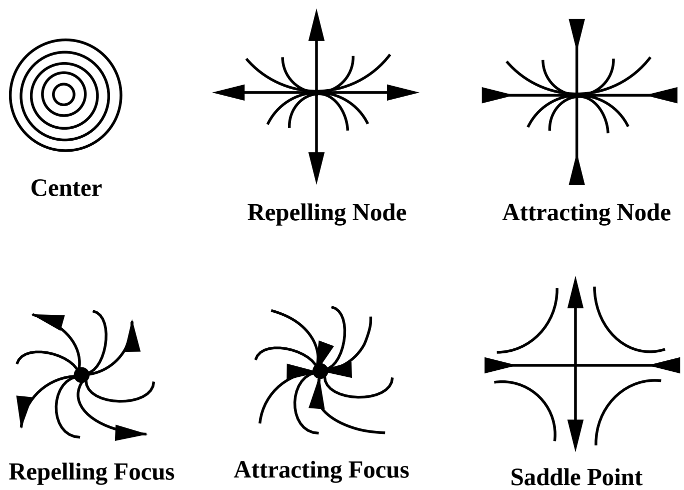

Figure 1: Critical Point Classification

We will produce two sets of visualizations, one set consisting of uniform Cartesian sampling of the function and another set consisting of a uniformly random sampling of the function. The same number of samples will be taken in both visualizations. Visualizations will be produced by placing a vector icon at the sampled point, with the size and orientation of the icon given by the vector function. Sample visualizations are provided in Figures 2 and 3. For these example visualizations, the following vector equation which yield two critical points was used:

$$v_x = (1 - 2x^2)e^{-(x^2+y^2)} \tag{1}$$

$$v_y = -2xye^{-(x^2+y^2)} \tag{2}$$

Figure 2 demonstrates a Cartesian sampling of the functions above, with a total of 441 vectors being places (21 positions in each direction). Figure 3 demonstrates six instances of uniform random placement of the same number of icons for the equations above.

3.2 User-Study Development

For this project, two user-studies will be accomplished. The first, a force choice study, will attempt to identify which visualization method is best for identifying the number of critical points in a visualization. The second, a critical point location study, will attempt to determine which visualization method is best for the task of determining the center of all critical points within the visualization.

3.2.1 Force Choice Study

The task for this study is for the user to answer the following question: Are there exactly two critical points in this visualization (Yes or No)? The user will be shown visualizations consisting of a linear combination of 0,1,2,3 and 4 critical points with the following likelihoods: $P_0 = 0.125, P_1 = 0.125, P_2 = 0.5, P_3 = 0.125, P_4 = 0.125$. The likelihoods have been determined so that the user does not benefit by merely guessing.

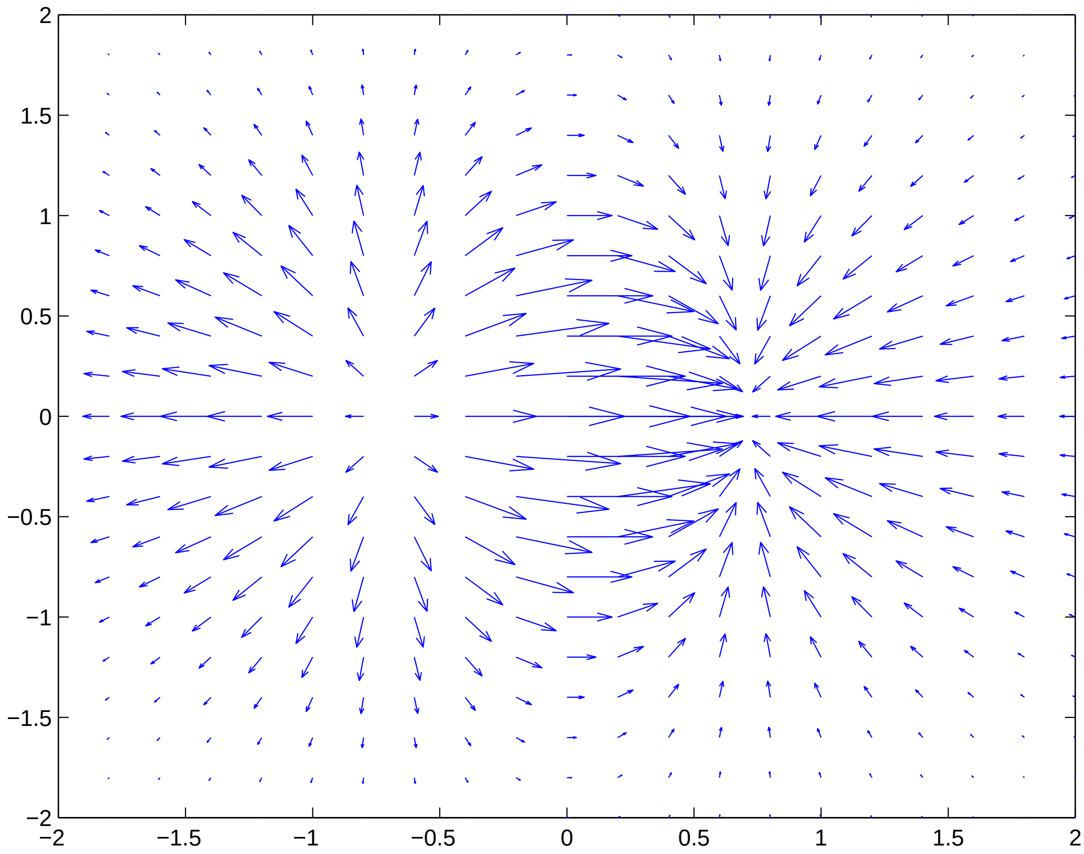

Figure 2: Cartesian Plotting

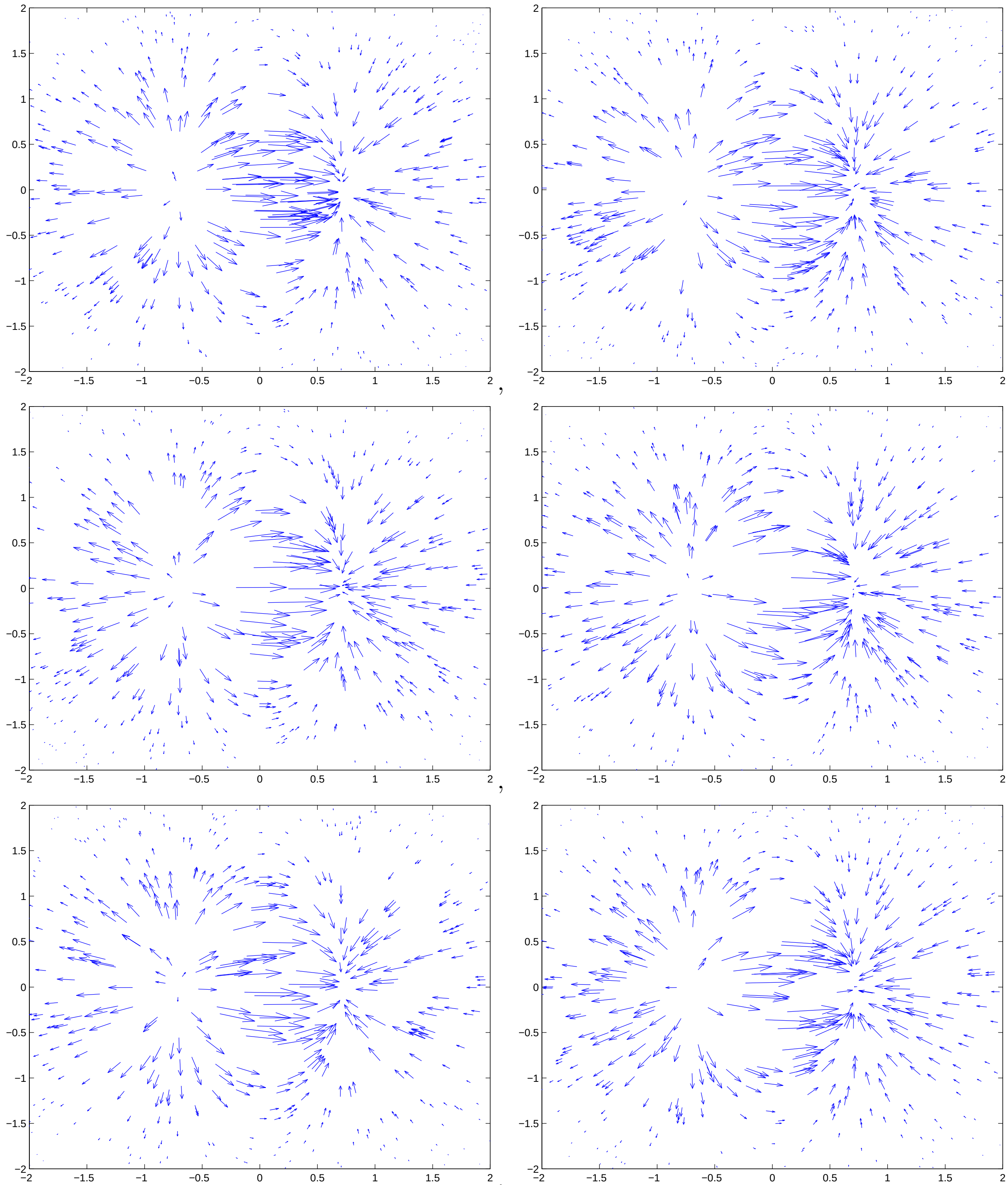

Figure 3: Plotting at Random Points (Uniform Distribution)

3.2.2 Critical Point Location Study

The task for this study is for the user to accomplish the following: Identify the location of all critical points in this visualization. The user will be shown visualizations consisting of a linear combination of 0,1,2,3 and 4 critical points with the following likelihoods: $P_0 = 0.2, P_1 = 0.2, P_2 = 0.2, P_3 = 0.2, P_4 = 0.2$. Both distance information between the user choice and actual centers and timing information will be collected.

3.3 Analysis of Results

Statistical analysis (mean and variance) will be accomplished on all results obtained.

4 Milestones

For this project, we propose the following six-week plan:

1. Week 1-2: Produce Visualizations
2. Week 3: Pilot User-Study
3. Week 4-5: User-Study
4. Week 6: Analyze Results

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CV for R.M. Kirby

Personal

Name: Robert M. Kirby II
E-Mail: kirby@cfm.brown.edu

Education

Brown University, Ph.D candidate in Applied Mathematics, Expected May 2002.
Advisor: George Em. Karniadakis, Professor of Applied Mathematics, Brown University

Brown University, Master of Science Degree candidate in Computer Science, Expected May 2001.
Advisor: Andries van Dam, Professor of Computer Science, Brown University

Brown University, Master of Science Degree in Applied Mathematics, May 1999.

The Florida State University, Bachelor of Science Degree; Major(s): Applied Mathematics and Computer and Information Sciences; Graduated *Summa Cum Laude*

Employment

Division of Applied Mathematics and Department of Computer Science, Brown University
September 1997 - present: Graduate Student

The Geophysical Fluid Dynamics Institute at Florida State University April 1997 - August 1997: Systems Manager

The Geophysical Fluid Dynamics Institute at Florida State University June 1992 - April 1997: Computer Programmer/ Research Assistant

Related Skills and Experience

During my graduate studies, I have participated in many fluid flow visualization projects which have led to publishing results on the use of both painterly techniques for two dimensional fluid flows and immersive virtual reality techniques for visualizing three dimensional fluid flows. Current work involves attempting to quantify through user-studies the quality of visualization methodologies.

CV for J. M. Tasman

Personal

Name: Joshua M. Tasman
Email: jmt@cs.brown.edu

Education

Brown University, Bachelor of Art Degree in Computer Science, Expected December 2000.

Employment

Kewalo Basin Marine Mammal Laboratory, University of Hawai'i at Manona May 2000 - August 2000: Research Assistant / Computer Programmer

Project Phoenix, SETI Institute September 1999 - December 1999: Computer Programmer / Research Assistant
Configuration Choices for the Allen Telescope Array D.C.-J. Bock, M.C.H. Wright, W.J. Welch and J. Tasman, poster presented at the workshop "Technology Pathways to the Square Kilometre Array", Jodrell Bank Observatory, UK, August 2000.

Visual Perception Lab, Brown University Department of Cognitive Science January 1998 - May 1998: Research Assistant

Human Neurophysiology Lab, University of Louisville Medical School, June 1993 - August 1993, June 1994 - August 1994: Computer Programmer / Research Assistant

Related Skills and Experience

As an undergradate, I have developed my programming skills both in the academic and research environments. I have studied computer graphics and software engineering in the classroom, and have experience working with complex, real-world data sets such as dolphin echolocation acoustics, radio telescope array configuration simulations, and human EEG signals.

Collaborator Support

David H. Laidlaw, Stephen Robert Assistant Professor, Department of Computer Science

Mike -

I will indeed participate in your proposed CS237 project to investigate different placement strategies for icons used to visualize 2D fluid flow.

-David

--

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William H. Warren, Professor, Department of Cognitive and Linguistic Sciences

I am happy to serve as a consultant to Mike Kirby on his user study on vector placement for CS237. This is a natural continuation of our previous work on flow field visualization, asking a very specific question that is in need of an answer.

-- Bill

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