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PI/PD Name: David H Laidlaw

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race: (Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status: (Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☒ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

Check here if you do not wish to provide any or all of the above information (excluding PI/PD name): ☐

REQUIRED: Check here if you are currently serving (or have previously served) as a PI, co-PI or PD on any federally funded project ☒

Ethnicity Definition:
Hispanic or Latino. A person of Mexican, Puerto Rican, Cuban, South or Central American, or other Spanish culture or origin, regardless of race.

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PI/PD Name: Jan S Hesthaven

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race: (Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status: (Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☒ None

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PI/PD Name: George E Karniadakis

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☐ Not Hispanic or Latino

Race: (Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status: (Select one or more)
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- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☒ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

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PI/PD Name: Andries van Dam

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race: (Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
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- ☐ Native Hawaiian or Other Pacific Islander
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Corrected : 01/22/2009

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 09-1

NSF 09-502 **01/22/09**

FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)

CNS - MAJOR RESEARCH INSTRUMENTATION

FOR NSF USE ONLY

NSF PROPOSAL NUMBER

0923393

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
01/22/2009	1	05050000 CNS	1189	001785542	05/27/2009 10:13am S

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)

050258809

SHOW PREVIOUS AWARD NO. IF THIS IS
☐ A RENEWAL
☐ AN ACCOMPLISHMENT-BASED RENEWAL

IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE

Brown University

AWARDEE ORGANIZATION CODE (IF KNOWN)

0034017000

ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE

Brown University
164 Angell Street
Providence, RI. 029129002

NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE

PERFORMING ORGANIZATION CODE (IF KNOWN)

ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions)
☐ SMALL BUSINESS ☐ MINORITY BUSINESS
☐ FOR-PROFIT ORGANIZATION ☐ WOMAN-OWNED BUSINESS

☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **MRI: Development of a Next-Generation Interactive Virtual-Reality Display Environment for Science**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 1,999,983	48 months	09/01/09	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

☐ BEGINNING INVESTIGATOR (GPG I.G.2)
☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)
☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D, II.C.1.d)
☐ HISTORIC PLACES (GPG II.C.2.j)
☐ EAGER* (GPG II.D.2) ☐ RAPID** (GPG II.D.1)
☐ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date _____
PHS Animal Welfare Assurance Number _____
☐ HUMAN SUBJECTS (GPG II.D.7) Human Subjects Assurance Number _____
Exemption Subsection _____ or IRB App. Date _____
☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j)
_____
☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.G.1)

PI/PD DEPARTMENT
Computer Science Department

PI/PD FAX NUMBER
401-863-7657

PI/PD POSTAL ADDRESS
Box 1910

Providence, RI 02912
United States

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME **David H Laidlaw**	**PhD**	**1995**	**401-354-2819**	**dhl@cs.brown.edu**
CO-PI/PD **Jan S Hesthaven**	**PhD**	**1995**	**401-863-2671**	**Jan.Hesthaven@Brown.edu**
CO-PI/PD **George E Karniadakis**	**PhD**	**1987**	**401-863-1217**	**gk@cfm.brown.edu**
CO-PI/PD **Andries van Dam**	**Ph.D.**	**1965**	**401-863-7640**	**avd@cs.brown.edu**
CO-PI/PD				

Electronic Signature

CERTIFICATION PAGE

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the Authorized Organizational Representative or Individual Applicant is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), nondiscrimination, and flood hazard insurance (when applicable) as set forth in the NSF Proposal & Award Policies & Procedures Guide, Part I: the Grant Proposal Guide (GPG) (NSF 09-1). Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, Section 1001).

Conflict of Interest Certification

In addition, if the applicant institution employs more than fifty persons, by electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of the NSF Proposal & Award Policies & Procedures Guide, Part II, Award & Administration Guide (AAG) Chapter IV.A; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be dislosed to NSF.

Drug Free Work Place Certification

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Drug Free Work Place Certification contained in Exhibit II-3 of the Grant Proposal Guide.

Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Debarment and Suspension Certification contained in Exhibit II-4 of the Grant Proposal Guide.

Certification Regarding Lobbying

The following certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

Certification Regarding Nondiscrimination

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative is providing the Certification Regarding Nondiscrimination contained in Exhibit II-6 of the Grant Proposal Guide.

Certification Regarding Flood Hazard Insurance

Two sections of the National Flood Insurance Act of 1968 (42 USC §4012a and §4106) bar Federal agencies from giving financial assistance for acquisition or construction purposes in any area identified by the Federal Emergency Management Agency (FEMA) as having special flood hazards unless the:

(1) community in which that area is located participates in the national flood insurance program; and
(2) building (and any related equipment) is covered by adequate flood insurance.

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant located in FEMA-designated special flood hazard areas is certifying that adequate flood insurance has been or will be obtained in the following situations:

(1) for NSF grants for the construction of a building or facility, regardless of the dollar amount of the grant; and
(2) for other NSF Grants when more than $25,000 has been budgeted in the proposal for repair, alteration or improvement (construction) of a building or facility.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME **Poovenderan S Nair**	**Electronic Signature**	**Jan 22 2009 4:58PM**

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER
401-863-3141	**Segran_Nair@Brown.edu**	**401-863-7292**

* EAGER - EArly-concept Grants for Exploratory Research
** RAPID - Grants for Rapid Response Research

Project Summary

This proposal describes the development of a world-class interactive large-field-of-view 85 megapixel immersive virtual-reality environment targeted primarily for scientific research. Two decades of research at Brown and elsewhere have established the significant value of immersive displays as a research tool in many scientific domains.

This research has also identified a set of currently unmet needs that block application of such displays to new problems and domains. These needs are: high display resolution, brightness, contrast, and size; fast, responsive tracking with high accuracy and low latency; ease of use in working with new kinds of data; and reliability. All but a few multi-million dollar systems existing today fall significantly short in one or more of these areas, and those few high-end systems will not match our proposed display's color gamut, small physical space requirement, and lower cost to replicate.

The proposed display environment will address these needs and will help accelerate scientific work, research into innovative visualization methods for accelerating science in the future, and even in thus-far under-served disciplines by leveraging the fundamental advantages of immersive, large-field-of-view visualization and body-centric human-computer interaction. The system will support more natural and effective interaction with data than today's 3D point-and-click wand-driven CAVEs™ by maximally utilizing as appropriate full-body, motion-captured user interactions and gestures. More display information will be made accessible to the human visual system with less user effort by matching or exceeding the perceptual qualities of a modern LCD monitor.

We will integrate commodity projectors to develop an immersive stereo display with the perceptual resolution of a desktop display and far superior brightness and contrast. Ease of use and reliability will be achieved by integrating existing and proposed software tools for creating virtual-reality applications quickly; the new tools will be distinguished by a) their simplicity, b) support for a spectrum of displays (desktop through CAVE™), and c) rich support for gestural interaction. We will develop a monitoring process that identifies potential problems among the many interacting hardware and software components to identify and address problems before they delay instrument users.

Users of the proposed system will include planetary geologists, systems biologists, brain scientists, cell and molecular biologists, biologists studying animal motion (including flight), fluid dynamicists, bioengineers studying arterial hemodynamics, visual designers developing interactive techniques for scientists, digital literary artists, and visualization and interaction researchers. All of the potential users work in Brown's context of a merged research and education process, in which students actively participate.

Intellectual Merit: The intellectual merit of the proposal begins with a promising and novel approach to build an instrument that will address the serious limitations of existing displays. With those limitations reduced or removed, it is expected that multiple avenues of scientific inquiry that are blocked or severely restricted will advance rapidly. Within interaction research, experiments using the system will establish the appropriate levels of display technology (e.g., resolution, interactivity, or stereographic display) needed for different classes of scientific analysis. We will also create novel, demonstrably useful, rich, and expressive interaction, visualization, and analysis techniques that truly leverage the human visual and motor systems in VR. These techniques will apply to individual scientific domains at Brown and more broadly will be distributed on SourceForge to help accelerate scientific progress nationwide. Finally, we will distribute on SourceForge the software environment for developing multi-display applications and the monitoring system for ensuring reliability. We will publish the knowledge about building multi-screen displays.

Broader Impact: The broader impacts resulting from the proposed activity will come from new advances in all of the scientific disciplines of the users listed above. These may include a better understanding of: the workings of cells and the genes and proteins they contain, which could have consequences that improve quality of life broadly; behavior of fluids in arteries and around moving animals; animal locomotion, which could lead to improved biomimetic locomotive, floating, or flying vehicles; the wiring of the human brain, how it affects human capabilities, and how it can degrade; and Mars.The proposed efforts will produce a new generation of scientists who can better analyze their research problems using sophisticated scientific visualization, computer scientists more cognizant of scientists' analytical needs, and artists and designers who can help accelerate the design process for immersive scientific visualization tools.

TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.B.2.

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

Project Description: MRI: Development of a Next-Generation Interactive Virtual Reality Display Environment for Science

David H. Laidlaw, Prof., Comp. Sci. (PI); Jan Hesthaven, Prof., Appl. Math and Dir. of CCV (Co-PI)
Andy van Dam, Prof., Comp. Sci. (Co-PI); George Karniadakis, Prof., Appl. Math (Co-PI)

Instrument Users: Gilad Barnea, Neuroscience; **Christophe Benoist**, Joslin Diabetes Center; **Kenneth Breuer**, Engineering; **John Cayley**, Literary Arts ; **Ronald Cohen**,Psychiatry & Human Behavior ; **Robert Coover**, Literary Arts ; **Stephen Correia**, Psychiatry & Human Behavior ; **Robert Creton**,Molecular, Cellular Biology & Biochemistry; **Fritz Drury**, Rhode Island School of Design,; **James Head**, Geological Sciences; **Sorin Istrail**, Computer Science; **Mark Johnson**, Molecular, Cellular Biology & Biochemistry; **Paul Malloy**, Psychiatry & Human Behavior; **Robert Paul , Psychology, U. Missouri**, St. Louis; **Ben Raphael**, Computer Science; **Peter Richardson**, Engineering; **Robert Reenan**, Molecular, Cellular Biology & Biochemistry; **Stephen Salloway**, Clinical Neuroscience; **Arthur Salomon**, Molecular, Cellular Biology & Biochemistry; **Mel Slater**, Univeritat Politecnica de Catalunya, Barcelona, Spain; **Sharon Swartz**, Ecology & Evolutionary Biology; **Kristi Wharton**, Molecular, Cellular Biology & Biochemistry

Introduction to Revised Proposal

This proposal is a revision of an MRI proposal submitted last year. In this introduction, we paraphrase reviewer feedback, outline changes we made in response, and point to the relevant sections that were changed. Note that substantive changes are indicated by change bars in the margin.

First, we were encouraged by the "Highly Competitive" overall evaluation and the many strengths that were described in the review summary provided by the program officer. Under intellectual merit, these included the novel choice and integration of hardware; the increase in brightness, resolution, contrast, and tracking; the advancement of virtual reality working environments; the monitoring process for improving reliability; the improvements to existing scientific applications; and a better understanding of appropriate levels of display and interaction for different applications. Under broader impact, these included satisfying the increasing demands of computational science research, scientific advances in the many application areas, and dissemination of the instrument development work.

Second, we describe revisions made in response to specific issues raised in the review summary:

- *Insufficient detail in broader impacts*. The description of broader impact in the project summary has had more detail added to make it less perfunctory and the individual scientific applications more clearly identify their impact (Sec. a.1).
- *Amount of software support perhaps too low*. We better describe the software architecture and the portions that are already complete (Sec. b.2) and believe that the proposal staffing is now consistent with this.
- *Insufficient detail, clarity, and motivation for the software environment architecture and interactivity*. Sec. b.2 now describes the software environment architecture more clearly as well as its use and how data is incorporated.
- *Loose schedule in the first year.* The schedule for the first year (Sec. d.2) has been made more specific and tight.
- *Vague "hard dollar" amount of cost share*. The budget justification now describes the cost sharing more concretely. The letter describing institutional support now includes all cost sharing.
- *Not enough detail about how students are informed*. Sec. a.3 now collects the teaching applications and describes student experiences more clearly.

Third, we address several recommendations from the summary review that have not already been addressed above. The following specific recommendations were implemented.

- We added more details regarding the basic scientific research projects that the project will stimulate, including their need for a Cave, their impact both intellectually and more broadly, and more details of the computational challenges.
- We summarized more clearly and prominently the results of user studies indicating the contexts in which immersion is critical and a Cave is preferred over a desktop display. See Sec. b.

- We updated our comparison with other sites, in particular Iowa State's C6 system (see Sec. b.3).
- Other issues have been addressed but are not summarized here for lack of space.

We note that the revisions outlined here as well as this introduction have necessitated that some detail be removed in other parts. We hope that that reduced detail in those sections will not be evaluated negatively.

a Research Activities

In this section we summarize the scientific research that will be enabled by the proposed immersive display environment. The proposed instrument will be used primarily for research involving interactive visualization of scientific data, but will also enhance education through use in academic courses (e.g., scientific computing and visualization), as well as projects in the arts that depend on immersive environments. The investigators in the scientific visualization projects will investigate new models and hypotheses, develop working prototypes of new visualization and interaction methods, evaluate the prototypes, and apply them to their scientific problems. In general, our projects are multi-year efforts funded by government or private sources. They are often collaborations between domain scientists and computer scientists who work to identify and then develop tools that address complex and important data understanding problems. The infrastructure that supports these research projects is integral to success and is detailed below.

Many scientists are overwhelmed by the data-analysis task. These scientists work with complex data consisting of massive amounts of scalar, vector, tensor, and higher-dimensional data; intricate 3D spatial relationships between features; time-varying data; and combinations of these and other attributes. Some systems biologists also work with huge information data sets that model, for example, signaling between the 100,000 human proteins, or commonalities and function proteins that are similar across animals. While automated data analysis of these kinds of data is a long-term vision, scientists will rely on interactive visualization tools to analyze data from experiments for the foreseeable future.

"Description and Needs" (Section b below) describes both Brown University's experience researching and publishing in the area of immersive scientific visualization as well as the key instrument needs for the research activities described in this section. The needs are supported by references to our previous research and research done at other sites.

Our proposed instrument will:

- permit examination of significantly higher-resolution and larger data sets using existing software;
- allow the development of new visualization and visualization interaction techniques for application to our research community's visualization problems;
- enable research on human-computer interaction and display environments that transcend the size, resolution, and brightness limitations of existing systems;
- extend capabilities of 1998 Cave for novel teaching applications in the humanities, science, and the arts;
- investigate limits of state-of-the-art immersive displays for scientific visualization;
- produce and disseminate easier-to-use, more reliable software for using multi-display instruments;
- develop and disseminate knowledge and expertise that will allow other sites to assemble appropriate display configurations.

In the following sections we list the science and teaching activities planned for the proposed instrument. Each activity involves research training with an estimated 6 graduate students working with PIs in each area, as well as undergraduates. Brown University has a strong history of undergraduate students playing a significant role in faculty research projects.

a.1 Science Activities

Biological Applications Involving Confocal Micrographs Biologists using confocal microscopy at Brown are a first example of a group of domain scientists who will benefit from the ability to visualize their 3D microscopy data in the proposed facility. Confocal microscopes capture 2D slices of biological specimens which can be "stacked" into a 3D representation of the specimen. The microscopes are in near-constant use by a group of about forty faculty. These instruments produce 20-40 datasets every day. At this point, automatic data analysis systems are not reliable. The human analysis of a series of optical sections is a major challenge to most researchers currently, and we have established that volume-rendered datasets

in the Cave provides a much more immediate understanding of complex spatial relationships that speeds up data analysis as well as future experimental design. A recent formal user study of experienced confocal data analysts found that subjects performed a sequence of scientific tasks significantly faster and more accurately in the Cave than at a conventional desktop. Based on collaborator Wharton and Kreiling's successes [PFK+08][KWC07], new faculty have expressed serious interest in analyzing their data in the Cave including Creton (Molecular Biology, Cell Biology, and Biochemistry (MCB)), Barnea (Neuroscience), Reenan (MCB), M. Johnson (MCB).

The proposed display would speed up biological scientists' research by helping them explore and understand complex 3D features and spatial relationships (relative to the conventional and mentally taxing practice of viewing individual slices or a 2D composite of all slices) more clearly and more quickly. Our 1998 Cave is inadequate primarily because of the dim, low-contrast display but the proposed instrument's additional resolution will also be useful as confocal datasets increase in size.
Estimated annual users: 10 faculty, 2 postdocs, 100 students. Funding: DOE.

Impact:	Greater understanding of developmental biology processes.
CS challenge:	Management and interactive rendering of large datasets; visual abstractions for time-varying multi-valued volume data.

Computational arterial modeling Computational arterial modeling will leverage the proposed Cave for both 3D mesh generation tasks and detailed visualizations of biological flow simulation results and sensor data. Modeling the human arterial tree using both generic and patient-specific geometries and multiscale modeling of atherosclerosis are active areas of research that will benefit from the proposed facility. In particular, the orders-of-magnitude larger data and more complete models (e.g., including platelets and red blood cells in simulations) present several visualization challenges called out in the table below. One investigator (Richardson) has decades of experience of laboratory work in this area [TNS+78] [Ric80][RL83][RDB89] [RC90][DSD+91][DRW+93] [Ric02a][GR06]. The team has done some preliminary work in this area [FKL+00][FRS+03][Ric02b] [RPKL06][SFR+02]. Richardson has identified a number of research problems that are not practical to study in the physical modeling situation, but would be possible to investigate with a virtual cardiovascular laboratory enabled by the proposed instrument. Collaborators in this domain include Hesthaven, Karniadakis, Richardson, and Laidlaw and their research groups and Drs. Madsen and Anor, Department of Neurosurgery, Children's Hospital in Boston, and Dr. Jayaraman, Department of Diagnostic Imaging, Rhode Island Hospital.

Our 1998 Cave has proven inadequate for data analysis by domain scientists and researching arterial flow visualization methods as broadly as we need to because of its dim, low-contrast, low-resolution display of geometries, colormaps, surface textures, and text. In particular, designers from the Rhode Island School of Design (RISD) in Providence are co-PI's on projects and together with their students and colleagues play an integral role in our development of visualization methods [AJLD08][KAM+08] [AJLD05][LdT+04][JAL+03] and with our 1998 Cave we have been unable to implement and evaluate (or "crit") their visualization ideas in many cases.
Estimated annual users: 3 faculty, 1 postdoc, 30 students. Funding: NSF, DOE.

Impact:	Greater understanding of human circulatory system.
CS challenge:	Modeling flow through patient-specific geometries at high spatial and temporal resolution; management and interactive rendering of large datasets; visual abstractions of surface quantities simultaneously with time-varying 3D vector field data; visualization at multiple scales. display of uncertainty

Kinematics and Fluid Dynamics of Bat Flight The study of bat flight is a third driving domain application. Data analyzed include 3D kinematic measurements of bats performing under controlled conditions, 2D slices of 3D flow measurements in the bats' wakes, and full 3D fluid flow simulations of the air surrounding them during flight. In bat flight one is interested in the multiscale vorticity field as it determines the lift generated by the bat. Lift is the primary quantity of interest for biomimetically driven design concepts that may have application in developing novel flying machines that leverage flapping for hovering, avoiding obstacles, and managing turbulence. This activity builds on Air Force funded research at Brown University.

Over the last five years we have leveraged the 1998 Cave funding to develop a series of tools for visualizing the bat kinematics and flow [FKL+00][FRS+03] [SFL+04a][RPKL06]. Body-centric interaction, in which the user uses everyday movements to move through and interact with a virtual world, has helped in making analysis easier; however, the poor tracking accuracy has hindered navigation and the dim, low-contrast imagery has limited effective visualization. Collaborators in this domain include Swartz and Breuer.

Our 1998 Cave is inadequate for the same reasons in computational arterial modeling above.
Estimated annual users: 3 faculty, 1 postdoc, 50 students. Funding: NSF, Air Force, Keck Foundation.

Impact:	Deeper understanding of the flying capabilities and behavior of bats and transfer of knowledge to flying machines.
CS challenge:	Capturing detailed models of in-vivo flying bats; accurately simulating airflow around bats; interactive rendering of large, time-varying datasets; same visualization challenges as listed for arterial flow application.

Systems Biology A fourth driving application area is systems biology. We believe that it has the potential to accelerate discovery in the nascent area of proteomics. The 100,000 different proteins in humans can signal one another in several different ways, often at different sites. Many proteins are similar across mammals, but they are not identical. Identifying interactions and analyzing how they function all together would explain much of the function of the cell. A display of the resulting graph of interactions among all proteins, sometimes called the interactome, would be able to display much more of it than we currently can . The prototype visualization analysis application we have developed helps scientists selectively study parts of the interactome. However, it is limited by the resolution of current displays. The proposed instrument will provide a display that can reach the resolution demands of these data-intensive analyses. Collaborators include Salomon, Raphael, and Benoist.
Estimated annual users: 4 faculty, 1 postdoc, 20 students.

Impact:	A greater understanding of how cells communicate and function.
CS challenge:	Interactive visualization methods for large, multi- graphs and associated meta-data.

Functional Mapping of the Cell the Center for Computational Molecular Biology at Brown University aims at creating a comprehensive set of interactive tools for the post-genome sequence era of Genomics, towards building the functional maps of the cell. In this enterprise, high-performance computing intertwined with the most advanced capabilities in visualization are a must for creating the new workflow, annotation, modeling, and simulation paradigms. We face multiple visualization challenges including protein structure visualization [TCE+01][IDLD07]. VMD software (http://www.ks.uiuc.edu/Research/vmd/) will be leveraged for protein visualization, as well as custom software under development at Brown (The Cellarium Project's SMPL which is a first building block of a programming language for genomics and The Cyrene Regulatory Genome Browser Project). Collaborators include Istrail.

The proposed instrument would help system biologists display hundreds of thousands of proteins in a higher density and study the interaction in a clearer manner (through the bright, high-contrast display), and the much clearer display of tens of thousands of textual characters associated with models would benefit from the increased display resolution.
Estimated annual users: 2 faculty, 20 students. Funding: NSF.

Impact:	A functional map of the cell.
CS challenge:	Multi-scale visualization of dynamic processes; molecular simulations.

White-Matter Anatomy Analytics The analysis of differences in white-matter anatomy is another driving application area. Creation of measures for quantifying anatomical and functional differences in white matter has potential applications to the study of development and function of the brain. In a number of collaborations among brain scientists and computer scientists, tools have been developed that combine familiar sectional images with 3D geometry that displays the white matter structures that connect different parts of the brain [ZDK+01] [ZDL03][Zha06]. By interacting with these structures, identifying substructures, and quantifying their characteristics, we have begun to create quantitative measures of white matter that can be used to track changes due to development, aging, and pathology.

These measures rely on interactive analysis. Currently, this is done on desktop systems because users prefer the brightness, resolution, and contrast of those displays [DJK+06b] even though they report virtual

reality interaction with human-scale models helps interpret the complex geometric models representing neural structures. The proposed system will provide the "best of both worlds and make it the instrument of choice for this research by enabling interactive analysis of bright, high-resolution, immersive visualizations of intrinsically 3D white matter structure of. Collaborators include Correia, Salloway, Cohen, Malloy, and Paul.

Estimated annual users: 5 faculty, 1 postdoc, 20 students. Funding: NIBIB (bioengineering at NIH).

Impact:	Greater understanding of neural connectivity and its implication.
CS challenge:	Automated and semi-automated analysis of diffusion tensor MRI data to identify connections between different parts of the brain.

Planetary Geology Planetary geology research is currently undergoing a revolution fueled by the acquisition of extremely high-resolution (approx. 10M/pixel) datasets acquired by the HRSC and MRO camera instruments. With the upcoming missions to the Moon and renewed interest in manned missions, future collaborations with NASA on astronaut training and management and visualization of high-resolution datasets is an extremely promising area of research. The goal of the NASA-funded Advanced Visualization for Solar System Exploration and Research (ADVISER) project at Brown is to put planetary geologists on or near the surface of remote planetary bodies and to provide them with tools that can enable them to gain insights into geological processes. Visiting planetary surfaces in immersive virtual reality helps them to apply the valuable field training geoscientists have by regaining the perspective that is lost in flat 2D images and narrow field-of-view displays. The ADVISER system has been used extensively over the past three years by researchers in Professor Jim Head's group for both research efforts and novel educational efforts. The proposed Cave will permit the continuation of our work by allowing us to present both significantly higher quality pixel data (due to the increased dynamic range) as well as greater detail available in the progressively higher resolution planetary image data which would not be displayable in our current Cave.

[HIVDF$^+$] and [FPH$^+$06] highlight geological themes that we have pursued over the past three years. Collaborators include Head and van Dam.

Estimated annual users: 2 faculty, 100 students including classes. Funding: NASA.

Impact:	Enabling application of in-situ, field techniques to inaccessible locations.
CS challenge:	Large geoscience data management and interactive rendering. Batch processing of thousands of high-resolution satellite images. Highly-detailed 3D reconstruction from stereo pairs.

Scientific Visualization and User Interaction Laidlaw, Hesthaven, van Dam, and Karniadakis, together with other collaborators at Brown, will advance the state-of-the-art in scientific computing, immersive visualization, and human-computer interaction. Our long term vision for complex data analysis is a human-computer partnership [vFL$^+$00] where the human guides the computer to identify potentially interesting types of features, the computer locates and displays such features, and the process iterates, spinning off hypotheses, ideas for new experiments, and insights about the phenomena under study. The development of this vision requires advances in multiple areas including (semi-)automatic feature detection, scientific data visual representations, and user interaction in immersive environments, where keyboard and mouse-based interfaces do not work well.

The domain science areas will guide the work through both individual and common scientific visualization and user interaction needs. Our approach will be based on close collaboration with domain scientists [Bro96]; building on artistic illustration concepts; supporting natural interaction techniques like gestures, direct manipulation, and speech; doing formal user evaluations to help measure progress; and experimentally testing hypotheses about the use of interaction and immersive displays. We have significant experience researching all the above-mentioned problems [VALJ02][ZDK$^+$01] [SFL$^+$04a][HIVDF$^+$][FPH$^+$06] [KKL03] [KAM$^+$01][KKL04][LAKZ01] [ZLAK02][KSF][DJK$^+$06b][PFH$^+$07][PFK$^+$08][SFK$^+$05b].

The proposed instrument will have many advantages for this work. First, it will let us implement more completely the range of visualization ideas developed with artists and other visualization specialists which we seeked to implement with our 1998 Cave but it lacked the necessary visual fidelity. Second, the instrument would make possible many new opportunities for user interaction research through the proposed tracking system whereby we could unobtrusively and accurately track almost any object that could help

with more natural interaction with immersive worlds (e.g., hands, fingers, a Tablet PC stylus, feet, and other props). Finally, the proposed instrument is arguably the "ultimate display" for doing system and technique evaluations in that more than any other Cave-like display it would let us carefully control display parameters similar to [PPW97] to really test the effects of fundamental display attributes like field-of-view, resolution, brightness, and contrast. Unfortunately, many researchers and graduate students have turned to other areas because of limitations due to our 1998 Caves old technology– an exciting new instrument will attract researchers back to the system to explore new ideas it makes possible.
Estimated annual users: 5 faculty, 3 postdoc and research staff, 8 students. Funding: NSF, DOE, NASA, IBM, Keck Foundation.

Impact:	Techniques that advance the state-of-the-art for interactive visualization of complex data. A greater understanding of the benefits of Caves relative to conventional and less immersive displays.
CS challenge:	Highly interactive rendering of information rich visual scenes. Vision-based body tracking. Gesture recognition and processing.

a.2 Veteran Affaris: PTSD and Physical Rehabilitation In collaboration with Professor Albert Rizzo of Univ. Southern California and Dr. Roy Aaron of Brown University School of Medicine; Medical Director of Rehabilitation Medicine, Miriam Hospital; and the Providence VA Medical Center we are investigating applications of immersive virtual reality to post traumatic stress disorder (PTSD), gait research, and physical rehabilitation. Collaborators include van Dam, Aaron, Rizzo.

The proposed instrument will provide enhanced presence, crucial improvements in tracking accuracy and frequency, and permit the integration of a motion/gait-measurement platform while maintaining adequate vertical field-of-view.
Estimated annual users: 2 faculty, 3 students. Funding: DOD

Impact:	Improved physical rehabilitation and PTSD management for veterans
CS challenge:	Accurate motion capture and data analysis.

a.3 Teaching Activities Classes include both authoring experiences, where students use relatively simple non-programming authoring tools to create VR environments and interactions, and virtual-reality science experiences, where students use VR applications to explore data and learn how to do science.

CS137 - Virtual Reality Design for Science This course explores the visual and human-computer interaction design process for scientific applications in immersive virtual reality. This course is cross listed at Brown and RISD and co-taught by Laidlaw (CS), Drury (RISD), and Swartz (Biology).

Students learn to interact with scientists in designing and realizing applications in this new medium. The class studies the process of design from several perspectives; learn about some specific scientific problems; studies existing applications of scientific visualization and virtual reality; explores the medium of the Cave; creates designs for the scientific applications; critiques, evaluates, realizes, and iterates the designs; and culminates with a demonstration of final projects. Collaborators include Laidlaw, Drury, Swartz.

The proposed instrument would have a huge impact on the work produced from this course. We have learned from the four times this course has been offered that artists are severely limited in what they can implement using our 1998 Cave due to software and display constraints. In the course, ideas are typically formulated with traditional medium (e.g., charcoal sketches, oil paints, etc.) and then transferred to the immersive environment. Students and faculty are currently frustrated both trying to realize their concepts and often achieving only a crude approximation of their intent due to the brightness, contrast, resolution, tracking, ease-of-use, and reliability limitations of the 1998 Cave.
Estimated annual users: 4 faculty, 3 postdoc, 9 students.

Impact:	Student immersive visualization ideas can be fully realized.
CS challenge:	Incorporating data-driven models from real-world science problems and providing an authoring platform that design students can use without programming.

Planetary Geology The system is used for novel educational efforts in Geosciences 5 ("Introduction to Mars, Moon and Earth"). Three hundred undergraduate students have used the Cave system to virtually explore the surface of Mars. An informal user study of 90 Geo5 students aimed at comparing insights gained from standard teaching media as well as the Cave found that using a conventional desktop and a Cave environment contributed significantly to the learning experience.

Impact:	Students get a visceral understanding of the surface of Mars.

Cave Writing In this course students use the Cave to design creative multimedia artwork. Some of the works and the easy-to-use hypertext authoring system have been published at SIGGRAPH [BBC+06] [CCG+03]. John Cayley, one of the most senior and respected persons in electronic writing, is now on the Brown faculty and will be continuing creative work in the Cave. Collaborators: Coover, Cayley, Howe. Estimated annual users: 2 faculty, 20 students.

Impact:	Students explore a new medium for producing works of art.
CS challenge:	An easy-to-use authoring environment that integrates multimedia into a time-varying, interactive experience.

a.4 Results from Prior NSF Instrumentation Support Laidlaw was a Co-PI on NSF award BCS-0521432 (PI:Jerome Sanes), $2M, 9/2005-8/2006, "Acquisition of a 3T MRI System." The Brown MRI Research Facility (http://brainscience.brown.edu/MRF/), directed by Jerome Sanes, handles all aspects of operations of the system. They coordinate scheduling and maintenance and oversee all research projects that use the system. Maintenance is by contract with the manufacturer, Siemens. Once acquisition and installation was completed, operations commenced and downtime has been limited to scheduled maintenance and nearby building renovations. The system is available for scheduled usage weekdays from 10-4. Instrument and protocol development work takes place outside those scheduled hours. Usage is ramping up as imaging projects are developed or migrated from other sites.

Hesthaven and Karniadakis were Co-PIs on NSF award 0421913 (PI: D. McClure), ending late 2006, "Scientific Computing Research Environment for the Mathematical Sciences (SCREMS): Enrichment and Integration of Computing Resources for the Mathematical Sciences." The Division of Applied Math at Brown acquired and installed research computing equipment dedicated to support of research in the mathematical sciences. No data is yet available on the usage, downtime, etc. but early indications are that the purchase has significantly increased the capabilities of the system and is fully functional and heavily used.

b Description and Needs

Below we describe the proposed display, then enumerate and support the specific needs that justify it. A common theme throughout the activities is the need for bright, high-contrast imagery in a large working space. Equally important is the need for higher resolution display–partially because of the great benefit to stereo viewing that textured surfaces have for enhancing the understanding of 3D form and also for high fidelity geometric models and clear display of text. Third, the need for very accurate, low-latency, wireless, light-weight (physically), 3D tracking of the full working space will give the most accurate view (through head-tracking) as users react to what they are seeing, and give the best interaction with 3D models through accurately body and input device movements. Fourth, applications must run at interactive rates or the illusion of a virtual environment is destroyed or worse (motion sickness may occur or users may stop using the instrument). In our experience about 20 frames-per-second (FPS) is a minimum and 30-60 FPS provides a much better experience. Finally, reliability and ease-of-use need to be much improved. The proposed instrument would provide orders of magnitude advancement over our 1998 Cave.

The technological leadership of the United States has been declining. Without the proposed display system, Brown will sacrifice its momentum in the area of interactive scientific visualization and continue the decline. We will lose the opportunity to effectively advance related scientific research that depends on scientists' pattern recognition ability as an integral part of the data-analysis and hypothesis testing phase. Over 50 peer-reviewed papers have been published about research in our current Cave and in related areas of scientific computing and algorithm development. Our results for quantitatively studying large, immersive environments are seminal; they have demonstrated some of the scientific areas and tasks that benefit from current immersive technology as well as identifying some areas and tasks that are impeded by technological

limitations. Immersion" Information-Rich Virtual Environments,. Visualization Quantitative Comparison Scientific Visualization Application Wayfinding in Complex 3D Models

We, and others, have also identified specific applications where scientists prefer the Cave[SFL+04b; FPH+06; PFK+08] as well as others where its limitations, intrinsic or otherwise, lead users to prefer other display types[DJK+06a; DLJ+03]. One experiment we are currently writing up compared our approximately 90-degree FOV, bright, high-contrast, high-resolution tiledwall to the dim, low-resolution, but over 180-degree FOV 1998 Cave for a confocal data analysis task; 11 of 12 subjects preferred the Cave, although would have preferred even more to combine the bright display of the tiledwall with the immersive nature of the Cave. While we have made great progress with the current Cave, it is simply unable to display and allow interaction with the large, high-detail datasets that arise naturally in all modern scientific endeavors.

b.1 Description of Proposed Display The new display environment will be built using revolutionary new stereographic DLP projection technology just released by Mitsubishi as projection televisions for the consumer market. These projectors use Texas Instruments 3D-DLP projection engines and a new laser-based light source that provides a much larger color gamut than other display systems, and a longer internal depth-of-field. 3D-DLP projection engines provide field-sequential stereographic projection at a field rate of 120 Hz. Projectors will be mounted behind rigid custom-built Blue Ocean screen material (Nippura Co. Ltd, Japan), which can provide a rear-projected floor in addition to walls. To minimize retroreflection, maintain black levels, and mitigate optical vignetting we will create a convex polyhedral display surface with interior face-to-face angles between 130 and 165 degrees. The vertical cross-section at standing eye-level will be a heptagon of 1920x1080 screens. The floor will use 8 projectors, for a total of 43 (nominally 85) million pixels. Each of these seven sides will have two trapezoids above and below, angling in at 15 and 20 degrees. Each panel will be driven by one nVIDIA display channel. Resolution of 35 pixels per inch will roughly match desktop 100 pixel-per-inch resolution because of larger viewing distance; color gamut, brightness and contrast will be much higher than even the best desktop monitor. The result can be thought of as 20/40 vision at 1.5m. A Vicon camera-based system with the capability of accepting, sampling and timestamping analog sensor input will be used for tracking the primary viewers head and interaction devices. The display will be driven by a Linux cluster with high-end graphics and high- bandwidth, low-latency network interconnect.

The new display, the "HepCave" (derived from "hepta") builds on the Calit2 StarCAVE, which uses a primary pentagonal cross-section, as well as preliminary experimentation done at Brown with tiled stereo and 3D-DLP displays. It differs significantly from the StarCAVE in the use of the 3D-DLP projection engines and the commercial projection TV optics. The use of 3D-DLP allows the use of field-sequential stereo (and superior optical field separation) rather than circular polarization, and most importantly, allows the installation of the HepCave in a much smaller room, as the depth required for the projector optics is roughly one foot. This allows us to install our display in a room which is only 6m x 6m, and use a rear/bottom-projected floor. It differs from the StarCAVE also in its use of a more complex topology with more than twice the number of tiles. Like the StarCAVE, we will mask image edges and mechanically align the images to the greatest extent possible. In order to obtain finer alignment using DSP we will develop a software analog of the timing control available for CRT projectors, and obtain a warp map, to be applied on the GPU, using a virtual remote control that interactively scales, warps and shifts the image to align a calibration pattern. Baseline alignment will first be done to a level laser line obtained with the use of construction trade instruments.

Several aspects of the proposed work take it beyond an acquisition to a riskier development process. First, selection and design of the screen components is crucial to the success of the project. This will take several months and will precede the final design of the screen mounting system and any necessary assembly jigs. Second, the work required to acquire and integrate these off-the-shelf parts is not merely assembly. Developing a reliable instrument of this complexity requires significant iterative design, evaluation, troubleshooting, and modification of both hardware and software. Third, we propose to develop a discipline-independent software library that augments a standard graphics library to support multi-display environments. It will include a prototype visualization application that will act as a template for users to more quickly make new discipline-specific applications. Fourth, we will create a suite of regularly run tests of both hardware and software to improve reliability. All four of these aspects of the work carry some risk;

one of the deliverables of the proposed work will be the knowledge gained and disseminated, which will permit other sites to more quickly and efficiently build future displays out of commodity components. All the software will be made generally available.

b.2 Need for Immersion Nearly a decade of research at Brown and elsewhere has established the significant value of immersive displays as a research tool in some scientific domains[Bro99; vFL+00]. Through formal or anecdotal user studies in some applications, we have determined that the benefits of large field-of-view and body-centered immersive 3D interactive visualization available in the 1998 Cave were sufficiently compelling to outweigh the resolution and brightness limitations[PFK+07][SFK+05a].

Previous research has demonstrated that the use of physically large displays with larger field of view improve spatial task performance[TGSP03][TGSP04]. Large displays offer better navigational aids and presence[CSR+03] [CRM+02][NBC06][TCR03] and help visual search in a spatial environment[PPSC99].

System evaluations should make conclusions about fundamental differences between systems, but too often IVR study results might be potentially drastically different if the common qualities of the technologies were in fact comparable (e.g., display brightness, contrast, and resolution). A desktop is generally *not* comparable with a Cave because of display and input device limitations. When discussed with our colleague Mel Slater, an expert in virtual environments and evaluation, he concluded that our proposed display would have great value for evaluations because: 1) it could in effect simulate all of the key environments (desktop, power-wall, Cave) of interest today and 2) it would allow the experimenter to vary a single display parameter at a time to much more effectively explore the cause of performance differences between display systems.

In one project we have been investigating the role of large body movement and level of immersion on data analysis of confocal volume datasets. Earlier studies showed the Cave outperforming Fishtank and desktop environments [PFK+08] and we hypothesized it was the body movement, learning through the encoding of structure in body movement that is afforded by the size and tracking of the Cave, compared to the space of the Fishtank even though it is tracked. The naturalness of the Cave viewing environment appears to be very valuable.

Need for Brightness and Contrast In a virtual environment, the light levels are dimmer than daylight because of brightness and contrast limitations of projector technology. Both factors are known to influence effective visual acuity [Dil92]. Low brightness causes poor performance and increases eye fatigue [Pos97][DS00][Duf00][CL98]. Significant improvement (3:2) in visual performance was observed even with a small differences (2:3) in brightness/luminance contrast [Duf00]. If colors are perceived under conditions of low illumination, failures of absolute color judgment could become more prevalent[Wic00] In addition, increase in the brightness and contrast also increases the range of polarity.

The dim, low-contrast projectors of the 1998-technology Cave allow as little as 25% of the information in an image to be perceived by viewers. Part of the lost information is color - at current brightness levels, colors are difficult to distinguish. Low resolution limits the complexity and size of displayed data and prevents optimal use of the human visual system pattern recognition abilities. Limited reliability and the high cost of developing scientific applications have also limited the ability of scientists to effectively use the 1998-vintage Cave. The movement of eyeball, head, and body supports multiple viewing perspectives and interactivity in an environment.

Need for Resolution The proposed equipment will provide one to two orders of magnitude improvement in brightness, contrast, and resolution. The change in visual impact is illustrated in Fig. 1(a) and 1(b). The blurry, dark, low- contrast image on the left that represents the current Cave will be replaced by the sharper, brighter, higher contrast image in the center. Scientists will be able to use significantly more of their perceptual abilities in addition to displaying order-of-magnitude larger scientific datasets.

It has been shown that high resolution displays benefit 2D information visualization tasks since more details are viewable at once and more distinct elements and attributes can be shown on the screen simultaneously[EK02][YN06][YHN07]. Such benefits can be further extended to 3D viewing conditions when combined with stereoscopic viewing and motion cues[War04]. High resolution displays also result in better task performance for text reading and navigation in 3D [BGBS02][SGH+03] [NBC06][YHN07]. When the task involves distinguishing between two items, higher pixel density results in higher accuracy[Pfa01]. Resolution is critical for very detailed imagery such as text and textured objects.

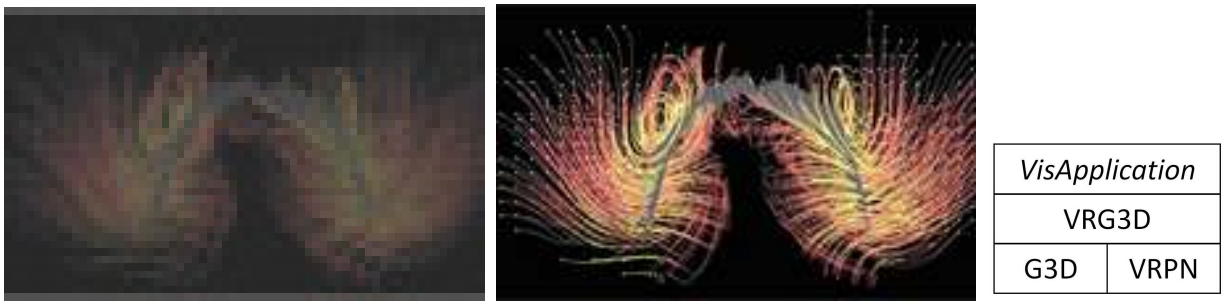

Figure 1: Approximate visual differences between (a) the current Cave and (b) the proposed display. (b) is 100dpi on paper, and shows, at an 18" viewing distance, the resolution one would see on a portion of a 30" LCD monitor or on the proposed display. Relative to the current Cave, pixels per viewing-solid-angle will be increased 16X, brightness and contrast more than 100X. Brightness and contrast will significantly exceed an LCD monitor. Color and detail will be more legible improving our scientific visualization capabilities. Controlled studies will be possible to help establish the relative value of different display configurations. (c) The proposed software architecture. VRPN provides interaction device access; G3D provides fast 3D graphics. Both are available online. Visualization applications are built on top of VRG3D, which adds support for multi-display tiled environments like Caves. A prototype application at the top level will provide a skeleton for new applications. This software architecture is discussed and motivated further in Sec. b.2.

In a text-intensive 3D system where pixel density was more critical than field of view or display size, the system with higher pixel density did not require zooming [SGH+03][NBC06] for text reading tasks.

In contrast to many 2D applications, we have found it is important to design a textured surface for nearly every visual element in VR applications to provide stereo-enhancing visual cues and encode more data [HE99][Int00]. Textures have been demonstrated to improve perception of 3D forms in monoscopic displays and showing multi-variant datasets [IFP97][KHSI04][Lai01], and we have found that textures also improve perception in stereoscopic displays where feature correspondence between eyes can be critical.

A recent study conducted in our lab examined the effects of resolution, viewing distance, and field of view on 3D vector field visualization. We found that a high resolution (40dpi) display that can display objects at a short viewing distance without blurring texture features gave the best performance. In [WM90], Ware used a high-resolution stereo display and found a speed increase for a 3D node-link diagram analysis task where previous studies on lower resolution stereo displays had only 3x speedup. Subjects also reported the high resolution display was much easier to look at than the low resolution display. The authors attribute this to the differences in spatial and temporal resolution. In our study [DJK+06b], the qualitative results showed subjects preferred a fishtank system over a Cave because of "perceived higher resolution, brightness and crispness of imagery, and comfort of use." The comfort factor may in part result from non-display factors, but the proposed Cave display should remove any perceived display quality differences from a fishtank system and perhaps would produce different results if the study was repeated.

Need for Fast and Accurate Tracking The proposed video-camera-based tracking system will have error throughout the tracked volume on the order of millimeters, a 100 to 1 improvement over our current wired magnetic tracking. The new system is also wireless, which reduces risk of injury and distraction. And, because the markers used in the system are about the size of a pencil eraser and easily attached to new devices, there are many opportunities to invent new input devices – the "keyboard and mouse" equivalent for the Cave still has not been invented. It will also be more ergonomic because each marker's weight is barely noticeable, whereas the current trackers are heavy and weigh down glasses and tracked objects. Scientists will benefit from more fluid and transparent interactions with their data; they will be able to analyze their data rather than be distracted by wires and tracker errors.

High precision non-intrusive tracking is literally still the most "direct" form of interaction, though many user-interface design solutions can compensate the needs (e.g., by target expansion). While our users are mostly scientists from various disciplines carrying out a rich set of tasks on variety of datasets and images,

customizable devices would have many advantages in meeting all users' needs. The tracking system should be light, easy to calibrate and wear.

We present some specific examples where prior work would benefit from the proposed tracking system. In [JFKZ01], it was very difficult to track feet with our current tracking technology, and we could not explore many of the kinds of gestural commands we envisioned. The quality of the prototype we developed was not even high enough to be pilot tested by people other than the authors. [ZLAK02] introduced the "FingerSleeve" which has several pop-through buttons attached, is light-weight, and fits snugly over one's index finger. This work concluded that the most important extension was to make the device wireless, which "would dramatically improve ergonomics." In another area of user interaction, we have frequently desired to link our pen-centric computing work [ZHH96][ZLJAFK02] [ZMHLJ][JZ04] with Cave applications, but two prerequisite capabilities include 1) accurate tracking of the pen-enabled display itself and 2) accurate tracking of a stylus without negatively impacting the ergonomics of a hand-held device such as a PDA or Tablet PC. The many dozens of users of CavePainting [KAM+01][KKL03], which uses a tracked paintbrush, had problems working in the full volume of the Cave because of tracker error and wired tracking. The proposed accurate tracking system could produce the true illusion of virtual in-air stroke painting. This would let users focus on their tasks and hopefully eliminate the cognitive overhead associated with compensating for the error between where a user intended to place strokes and where strokes actually appeared.

In a recent study run December 2007 that extended work in [PFK+08] which compared real-world neuroscience volume data analysis tasks in a Cave and on a Powerwall, user study subjects stated they disliked one system because the head-tracked stereo viewing caused the model to "move." After further testing, our explanation for such a perception of movement from head-tracked stereo viewing alone is some combination of tracking error, tracker lag, and inadequate rendering performance for the desired data size.

Need for Ease of Use Experienced users know well that Cave's are hard to use. Displays get misregistered, colors differ across walls, geometric alignment of projectors drift, tracking devices fail, and software development takes much longer than expected and is often a daunting task for beginners. Typically teams of support staff work to keep a Cave as productive as a conventional desktop system.

To address the current ease-of-use impediments that prevent wide usage of our Cave by scientists and others with demanding visualization needs, we will provide software access at three levels: commercial visualization software, a new scientific-visualization software development environment, and low-level development.

Commercial software. At the simplest level, commercial software Avizo (formerly Amira) will be available. New users considering the cave will be able to import their data in standard formats to Avizo, which provides established visualization and interaction techniques for studying the data. Brown's Center for Computation and Visualization (CCV) provides University-supported assistance to new users as part of their mandate. UIUC's freely available Visual Molecular Dynamics (VMD) package will also be used. CCV staff previously extended VMD with fast frustum culling for efficient rendering on tiled systems.

VR Application Development Environment We propose to develop and make available to the community an assemblage of two existing open-source software packages together with two new elements that will ease the creation, evaluation and use of new visualization and interaction techniques. Users who find that commercial solutions like Avizo are insufficient will move to this level of access, which will require programming. CCV will have some resources to assist at this level, but it is expected that most such development will require support from outside CCV to do significant work.

The high-level software architecture is shown in Fig. 1(c). It comprises four main components. First, freely-available VRPN provides access to numerous hardware interaction devices, including trackers, 3D mice, buttons, etc. Second, G3D (http://g3d-cpp.sourceforge.net/), a popular and widely used graphics library for desktop graphics application development, supports high-performance and advanced graphics (e.g., GPU programming). Third, VRG3D adds a cluster rendering capability. VRG3D is a very light-weight, platform independent, well-documented library providing an easy-to-use and reliable software development environment. A 2-year-old version already runs Cave programs and is used at Brown and the University of Minnesota. We propose to make it freely available via SourceForge alongside G3D, which is already available there.

The fourth component will be a visualization application framework analogous to Apple's MacApp. It will provide a tailorable example of an application, with VR navigation and interaction built in. Using this as a starting point will allow users to focus on the novel aspects of their visualization or scientific research, not on the VR issues that have already been solved numerous times. This framework application will also be made freely available. Several candidate prototypes of this application are currently in use in classes and in research. This software will run not only on the new immersive display, but also on researchers' desktops (Windows, Mac, linux), permitting smoother transitions between environments and easier "offline" software development.

There are a number of software packages supporting VR application development (CAVElib (http://www.vrco.com), VR Juggler/VRkit (http://www.vrjuggler.org), XVR (http://www.vrmedia.it/), OpenSG (http://opensg.vrsource.org/trac), FreeVR (http://www.freevr.org), and OpenScenegraph (http://www.openscenegraph.org)), but our experience identified issues that blocked our use in each. Our goal has always been to build on existing software wherever possible. We have experimented with or researched all of these libraries with our 1998 Cave. Most of the existing software tries to do too much or requires adoption of a complex programming model. VR Juggler, for example, is a large library compared to VRG3D and requires programmers to adapt to additional coding styles such as the "context-specific variables". CAVElib's procedural programming style, cost, and lack of higher-level functionality do not provide a strong foundation for development. FreeVR does not work with the standard Windows development tools so is not an adequate cross-platform solution. We have found that the architecture we propose limits functionality to a level that is sufficient, yet light-weight enough to work well in a quickly changing academic environment.

Lowest-level software. Finally, scientists who require even more control can develop applications directly via access to low-level graphics (e.g., OpenGL and GPU's) and operating system primitives.

A User-Friendly Kiosk. In addition to software, a touch-screen-based kiosk (currently in our Cave) will be developed to provide easy and quick access. These tasks will include turning the Cave on and off, routing rendering systems to the projectors, starting and stopping applications, running calibration software, and viewing system status (akin to VTK's quality dashboard, http://www.vtk.org/Testing/Dashboard/20080120-0300- Nightly/Dashboard.html), run applications, demos, homework assignments.

Need for Reliability Similar to ease-of-use, experienced users complain that Cave's are not as reliable as desktop systems. Software that ran yesterday may suddenly not run today and hardware systems fail similarly and my go undiscovered until a critical moment (e.g., demo or deadline crunch).

Therefore, also essential to the ease-of-use goal is a continuous monitoring process that will test and calibrate the instrument on a daily basis to ensure that the many disparate components are functioning and communicating. This will allow the identification of potential problems before they cost researchers time and aggravation. Together with the software platform, this system will ensure broader accessibility and greater utility for our researcher and student community.

The proposed Vicon tracking system has a simple calibration process that is easily performed in a minute or two. Computer systems will be monitored and maintained by nightly tests of software libraries and applications.

The Avizo commercial software product will provide us the most stable visualization platform http://www.tgs.com/products/avizo.asp). The in-house scripting languages and custom-code approaches described above will, by their nature, be less reliable, but they will also be subject to standard code development processes (e.g., nightly regression testing, revision control) to help quickly find and correct any reliability problems.

b.3 Other Sites with Caves There are several hundred Caves worldwide. Many are older Caves comparable to our dim, low-resolution 1998 Cave and differ from the proposed heptagonal Cave in that they have a rectangular, cuboid screen assembly which can introduce jarring discontinuities in imagery between display surfaces. Today's state-of-the-art Caves are high-resolution, tiled caves, most notably the 6-sided C6 at the Iowa State Virtual Reality Applications Center (100 megapixels, cuboid configuration), the StarCAVE at Calit2 in San Diego (68 megapixels, pentagonal prism configuration), and the 5-sided La Cueva Grande at Los Alamos National Laboratory (45 megapixels, cuboid configuration). Saudi Arabia's King Abdullah

University of Science and Technology (KAUST) Cornea Cave under construction will be the world's most advanced Cave and surpass Iowa's C6 in brightness. While our new display will have comparable gross resolution to the Iowa and KAUST displays (about 100 megapixels), the design is quite different in its use of consumer-market projection technology with laser light sources which will produce twice the color gamut of existing Caves and produce a bright and extremely vivid image. It will also advance VR technology by requiring less space for the projection staging, use far less energy, and consequently have little requirement for cooling or noise attenuation.

c Impact of Infrastructure

Brown has made a substantial investment in supporting scientific visualization and computation research, and the proposed instrument will make it possible to leverage and increase the momentum created by that investment. We have taken substantial steps toward understanding the value of immersive interactive human-computer interfaces for science, but have taken that research as far as possible using technology that is now a decade old. Computational and display technologies have advanced orders of magnitude in that time.

Only with current technology will we be able to understand and disseminate how best to build visualization systems in the service of science. For example, to experimentally answer the question "what resolution is needed?" for a scientific application, it is necessary to test at resolutions both above and below the optimum. With the high resolution instrument we have proposed, we believe we will be able to establish resolution needs. These needs, and the corresponding needs with respect to the other characteristics of displays, will be useful for creating the most effective and financially responsible scientific visualization systems of the future. This will inform work not only at Brown, but throughout the US.

With the proposed instrument we will be able to work in the context of those future displays to create interaction techniques and visualizations that will enable future scientific users to work more quickly and efficiently in the analysis phase of their science. Immediate impact will be on scientists at Brown followed by scientists studying similar problems elsewhere in the US. More broadly, our approach of collaborating across multiple disciplines to create tools that are as broadly applicable as possible should increase the impact to additional disciplines.

The multi-level access that we propose will lead to a software distribution that can be used to develop semi-custom applications using software component targeted at visual analysis of scientific data an immersive display environments. It will handle many of the most time-consuming development tasks, speeding the design and realization of new analysis tools. These benefits will accrue not only to Brown scientists, but to scientists across the country.

The facility monitoring approach that we propose to develop will also improve ease of use, further speeding software development as well as scientific use of our facility. We propose to build it on standards that will make it portable to other facilities, helping to more broadly improve ease of use of complex multi-component interactive display environments.

We have outlined a number of scientific research projects we expect to utilize the proposed instrument, and we have summarized their impact in Sec. a. In general, the new facility is expected to accelerate the advance of science in each of those research areas, particularly in the data analysis phase of the research.

Beyond those research projects, we anticipate that others will emerge as the display capabilities, the interaction paradigms, and the ease of use of the facility are developed. Users with similar research will likely follow our early adopters. As we identify the particular strengths of immersive interactive analysis, we expect that we will be able to map those strengths to other disciplines. We currently know that problems that are intrinsically 3D benefit from the use of stereo and head tracking; analogous maxims will point us at other fields that can benefit.

While it is implicit in the research projects, it is worth explicitly mentioning that the proposed instrument will provide an unusual teaching environment. Science students will learn about using visualization in the service of their science. Engineering and computer science students will learn about developing scientific visualization and analysis applications. Both groups will learn about collaboration by doing it; collaboration is a topic that is notoriously difficult to teach any other way. Brown has a long track record of successful collaborations like those proposed. Finally, the proximity of the Rhode Island School of Design will bring visual design experts into this learning environment. They have much to learn about science and software

but also have much to teach about visual processes. Our longstanding collaboration will continue to enhance our visualization, science, and teaching impact.

d Management Plan

This section presents our management plan and details the design and construction phases of the project. Over four years we will produce an innovative, auto-calibrated immersive Cave.

The proposed systems will be hosted in Brown's Center for Computation and Visualization (CCV). CCV was founded in 1998 to support Brown's growing need for support and development of high performance research computing and advanced visualization. It manages a number of Linux computing and visualization clusters, the 1998 Cave, and a recently constructed a 3x3 tiled stereo, head-tracked display wall. CCV has 4 full time technical staff members and one administrator. Hesthaven (Co-PI) is the academic Director of the Center. Plans for time allocation, reserved use, and multi user developments will follow the reservation system used for the existing visualization facilities in the center. The Center is funded primarily by Brown, which remains committed to continue its operation, and thus to support the management and operation of the proposed equipment.

d.1 Plans for making instrument readily available to other researchers Our system will regularly be viewed and used by many other people. We intend to use the same successful outreach model applied to our 1998 Cave with the proposed instrument.

At the research level, hundreds of external people have collaborated on research projects, experienced demonstrations of the immersive VR system (which can not be fully captured by papers, images or videos), and/or discussed any or all aspects (hardware, management, software, etc.) of building Cave-like systems at their sites. Several of the long-term collaborations are with outside users.

The 1998 Cave is used for demos to hundreds of prospective undergraduate and graduate students in Biology, Geology, Computer Science and Applied Mathematics. For example, Professor Karniadakis has an ongoing NSF-funded outreach program for middle and high-school students. The goal of the program is to inspire scientific inquiry through hands-on activities. Over 100 high-school students have visited the Cave as a part of that program, alone. Feedback from students indicates that they highly rate their learning experience in the Cave, and that it has helped them to appreciate the value of mathematics and domain sciences in their future career plans. The Cave is regularly used to host visits from local colleges and schools (Bridgewater State College, Hope High School, Moses Brown School, San Miguel School, Met School, RISD, etc.)

d.2 Schedule, Timeline, and Deliverables The following describes our schedule, timeline, and deliverables using absolute months into the project (months 0-11 is year 1, months 12-23 is year 2, etc.).

Year 1: (0.50 hw-person FTE +consulting) In year 1 we will finalize hardware decisions which will involve evaluating changes in availability since proposal submission; demonstrations of competing manufacturer's equipment; consultation regarding details of acquiring, machining, and integrating elements; and ordering the central display equipment (projectors, screen material, computers, trackers). The new equipment will be received late in the year. Through a process that minimizes system downtime, the 1998 Cave will be taken down and removed.

- finalize refined design (due month 3, 1.5 hw-person mos)
- order equipment (due month 5, 1.0 hw-person mos)
  screens; projectors;computer parts, racks; computer interconnect; computer-display connections; display-display interconnections; display calibration hardware/software; tracking hardware.
- receive equipment (due month 8, 0.5 hw-person mos)
- computer cluster assembled (due month 11, 1 hw-person mo)
  machine/construct/assemble computer supports; assemble computer hw with high-speed interconnect; install and test OS on cluster
- raised floor and other site preparations complete (due month 11, 1.0 hw-person mo)
- remove 1998 Cave (due at least disruptive time in year 1 TBD, 0.5 hw-person mo)

Year 2: (0.67 hw-person FTE, 0.58 swe-person FTE) In year 2 we will complete construction of the display, bring computer systems online, install TGS's Avizo and our own VRG3D software, and begin testing individual and linked systems.

- display hardware (due month 20, 4.5 hw-person mos, +machining/fab), (will start in year 1)
  detailed screen support specifications; detailed monitor support specifications; machine and construct screen supports; machine and construct projector platforms; mount screens and projectors; rough-calibrate projectors
- display-computer interconnect (due month 20, 0.5 hw-person mo)
- tracker system(s) (due month 20, 2-4 hw-person mos)
  install and test; calibrate; create hooks for monitoring and testing
- VRG3D display software library (due month 23, 6 swe-person mos)
  source-control setup; ability to distribute software configurable for arbitrary multi-display devices; implemented for new display configuration; multi-display optimizations incorporated; tracking incorporated; hooks for automated testing incorporated
- install Avizo (due month 23, 1 swe-person mos)

Year 3: (0.63 hw-person FTE, 0.63 swe-person FTE) Monitoring and testing reliability software will be designed, developed, and deployed. Application users and developers will be able to begin using the system.

- VRG3D-based example application (due month 26, 2 swe-person mos)
  identify additional problems with library
- distribution version of VRG3D available (due month 30, 1 swe-person mos)
- application users can now begin creating new applications
- monitoring/testing reliability software (due month 30, 2 hw-person mos, 4.5 swe-person mos)
  daily builds of software library and application; daily tests of machine accessibility (tracking, compute cluster functionality/performance, display device availability); touchscreen display of component status/availability; touchscreen access to troubleshooting options; easily extensible touchscreen interface for startup of (experiments, applications, demos, homework assignments) item display facet alignment system (due month 35, 5.5 hw-person mos)

Year 4 (0.17 hw-person FTE, 0.33 swe-person FTE) In year 4 we will finalize the software infrastructure, complete the auto-calibration system.

- software library changes (due month 36, 2 hw-person mos, 3 swe-person mos)
  (note that these are not maintenance, but part of the development process); feature request from specific application areas; application users will change apps to use them
- final software distributions to SourceForge (due month 47, 1 swe-person mos)

d.3 Staff and Background on technical expertise needed PI Laidlaw and Co-PI Hesthaven will manage the project. Laidlaw, who teaches software engineering and has worked in industry developing software for 4 years, will manage the software aspects of the project and Hesthaven will manage the hardware, integration, and operations aspects of the project.

The technical staff will require the specialized expertise to build and maintain the proposed instrument. The hardware engineer needs expertise in high-end projection systems, computer graphics cluster rendering systems, human-computer input devices (e.g., 3D tracking, hand-held 3D mice-like devices, interaction device data servers), and systems integration. The software engineer needs expertise in immersive visualization software development, graphics and GPU programming, knowledge of the current state of G3D and VRG3D, and software and graphics system testing. Each task in the 4-year plan will have some work for both staff members. See the "Schedule, Timeline, Deliverables" section above for more details.

The architect and technical lead for the project is CCV Associate Director Samuel Fulcomer (his bio is attached to the proposal). John Huffman is a CCV technical staff member who will assist Fulcomer in construction of the system. Both have extensive experience in the development, installation, and operation of large scale computation and visualization equipment, scientific computing and visualization. We will leverage our design with consultation with StarCAVE researchers at Calit2.

Andrew Forsberg of Brown Computer Science will be the lead software design and development effort. Forsberg has been a research staff member in the Graphics Group for twelve years and worked on developing immersive VR applications throughout that time.

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Education

1983 Sc.B. in Computer Science, Brown U., Prov., RI, *Topology and Mechanics.* Also completed requirements for an A.B. in Mathematics.
1985 Sc.M. in Computer Science, Brown U., Prov., RI, *Rendering Parametric Surfaces.*
1992 M.S. in Computer Science, Caltech, Pasadena, CA, *Material Classification of Magnetic Resonance VolumeData.*
1995 Ph.D. in Computer Science, Caltech, Pasadena, CA, *Geometric Model Extraction from Magnetic Resonance Volume Data.*

Experience

2008-present Professor, Computer Science Department, Brown University
2003-2008 Associate Professor, Computer Science Department, Brown University
2000-2003 Stephen Robert Assistant Professor, CS Department, Brown University
1998-2000 Assistant Professor, Computer Science Department, Brown University
1996-1998 Senior Research Fellow, Division of Biology, Caltech
1989-1996 Postdoctoral Research Fellow/Research Assistant, Computer Science, Caltech
1989-1993 Consultant Stardent/Advanced Visual Systems
1986-1989 Software Engineer, Stellar Computer
1983-1985 Research Assistant, Computer Science, Brown University

Honors and Awards

1998 Best Panel award at IEEE Visualization
2000 Appointed Stephan Robert Asst. Professor
2001 Best Case Study at IEEE Visualization '01
2001 NSF Career Award
2001 Best Layout and Best Scientific Presentation Exhibit Award at the American Society for Surgery of the Hand Annual meeting '01
2002 Computers and Graphics 2nd Best Paper
2003 Henry Merritt Wriston Teaching Fellowship
2004 Best Panel award at IEEE Visualization
2005 Best poster award at IEEE Visualization
2006 SIGGRAPH, ACM Student Research Competition, 1st place with PhD student Wenjin Zhou
20071st Place, NSF/Science International Science & Engineering Visualization Challenge, Informational Graphics, with student Misha Kostandov
2008 IEEE VGTC Visualization Technical Achievement Award

Selected Publications

- C. Jackson, D. Acevedo, D. H. Laidlaw, F. Drury, E.Vote, and D. Keefe. Designer-critiqued comparison of 2D vector visualization methods: A pilot study. In SIGGRAPH 2003 Sketches and Applications. IEEE, 2003.
- R. Kosara, C. G. Healey, V. Interrante, D. H. Laidlaw, and C. Ware. Thoughts on user studies: Why, how, and when. Computer Graphics and Applications, July/August 2003.
- C. Jackson, D. Karelitz, S. A. Cannella, and D. H. Laidlaw. The great potato search: The effects of visual context on users feature search and recognition abilities in an IVR scene. In Proceedings of IEEE Visualization, October 2002.
- D. Turner, I.H. Woodhouse, and D. H. Laidlaw. A synoptic visualization of fully polarimetric SAR. In Proceedings of IEEE IGARSS, 2002.
- D. H. Laidlaw, R. M. Kirby, J. S. Davidson, T. S. Miller, M. da Silva, W. H. Warren, M. Tarr, 2005. Comparing 2D Vector Field Visualization Methods, IEEE Transactions Jan 2005.

Other Publications

- van Dam, D. H. Laidlaw, and R. M. Simpson (2002). Future interfaces: an IVR progress report, *Computers and Graphics*,
- D. Keefe, D. Acevedo,T. Moscovich, D. H. Laidlaw, J. J. LaViola (2001). CavePainting: A Fully Immersive 3D Artistic Medium and Interactive Experience, Proc. 2001 Symposium on Interactive 3D Graphics.
- van Dam, A. S. Forsberg, J. J. LaViola, and R. M. Simpson (2000). Immersive Virtual Reality for Scientific Visualization: A Progress Report, *IEEE Computer Graphics and Applications*, 20(6), pp. 26-52.
- D. H. Laidlaw (2001), Loose artistic ``textures'' for visualization. IEEE Computer Graphics and Applications, 21(2):6--9.
- Upson, C., Faulhaber, T., Kamins, D., Laidlaw, D. H., Schleigel, D., Vroom, J. Gurwitz, R., and van Dam, A.(1989), The Application Visualization System: A Computational Environment for Scientific Visualization, *Computer Graphics and Applications*, 9(4).

Synergistic Activities

Last year a major revision of a new graduate/undergraduate class, *Interdisciplinary Scientific Visualization*, explored design issues in scientific visualization from two perspectives: illustration and computer science. The course was co-taught with Rhode Island School of Design (RISD) Illustration Department Chairman Fritz Drury. Together we worked with students from both RISD and Brown to design and realize new virtual reality interfaces for exploring 3D time-varying flow. Students learned about communicating and working with researchers across multiple fields. See course web page for more info: http://www.cs.brown.edu/courses/cs237.

Organized panel at Visualization '98 conference on Art and Visualization (best panel at conference). Participated in follow-on Visualization '99 and Visualization '01 panels. All probed issues of interdisciplinary collaborations for visualization.

Co-taught one-day course at premiere computer graphics conference, SIGGRAPH, about using art-based methods for scientific visualization. I led a two-hour session where approximately 80 computer graphics professionals used traditional art media (paint, charcoal, markers, chalk, etc.) to represent multivalued scientific data.

The final publication in c.ii. above describes AVS, a visualization software product that I was a principal developer on at Stellar Computer. It is widely used to process and visualize scientific data from many disciplines.

I have advised and continue to recruit out undergraduates for research projects both at Brown and, previously, at Caltech. Many of the projects have culminated in research publications. Several have been with women in computer science, a traditionally underrepresented group. I organize the Brown Computer Science undergraduate research opportunities web pages.

Collaborators and Other Affiliations

Collaborators and Co-Editors: Eric T. Ahrens, Caltech, Joseph W. Asa, Matthew J. Avalos, Caltech, C. Bajaj, U.Texas, Thomas F. Banchoff, Alan H. Barr, Caltech, Celia F. Brosnan, Albert Einstein College of Medicine, Kristen L. Cook, Caltech, Joseph Crisco, Brown, Bena L. Currin, Caltech, Mary E. Dickinson, Caltech, Paul E. Dimotakis, Caltech, John Donoghue, Brown University, Kurt W. Fleischer, Pixar, Andrew S. Forsberg, Brown, Geoffrey Fox, Felice Frankel, MIT, Scott E. Fraser, Caltech, Yuri M. Goldfeld, Caltech, Galen G. Gornowicz, Dreamworks SKG, Cindy Grimm, Washington U., Donald House, Texas A\&M, Victoria Interrante, U. of Minnesota, Russell E.Jacobs, Caltech, David Kremers, Caltech, Daniel B. Lang, Caltech, H. Marmanis, Brown, Carol Readhead, Cedars Sinai Medical Center, Sharon Swartz, Brown, Jerome Sanes, Brown, Jerry W. Shan, Caltech, Jeffrey M. Silverman, Cedars Sinai Medical
Center, Michael Tarr, Brown, J. Michael Tyszka, City of Hope Medical Center, Colin Ware, U. New Hampshire, William Warren, Brown, Iain Woodhouse, U. Edinburgh

Advisees: Daniel Acevedo-Feliz, Stuart Andrews, Cullen Jackson, Daniel Keefe, R. Michael Kirby, Georgeta Elizabeth Morai, Paul Reitsman, Eileen Vote, Song Zhang.

Advisors: Alan H. Barr, Caltech, Scott E. Fraser, Caltech.

Bibliographical Sketch of Jan S. Hesthaven

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Professional Preparation

- Technical University of Denmark, Computational Physics, MSc, 06/91.
- Technical University of Denmark, Computational Mathematics, PhD, 07/95.

Academic Appointments

- Director, Center for Computation and Visualization, Brown University — 10/06-present.
- Assistant, Associate, Full Professor of Applied Mathematics, Brown University — 07/99-present.
- Visiting Assistant Professor, Division of Applied Mathematics, Brown University — 08/95-06/99.
- NSF Postdoctoral Fellow (ASC), Division of Applied Mathematics, Brown — 08/95-06/98.

Honors and Awards

- Philip J. Bray Award for Teachning Excellence in the Physical Sciences for 2004-2005, Brown University - 03/04
- NSF Career Award, Division of Mathematical Sciences — 09/02.
- Manning Assistant Professorship, Brown University — 07/01
- Sloan Research Fellow, Alfred P. Sloan Foundation — 09/00.
- NSF Postdoctoral Fellowship, Division of Advanced Scientific Computing — 08/95.

Research Activities

- **5 Recent publications closely related to proposed research**

J. S. Hesthaven, S. Gottlieb, and D. Gottlieb, 2007, *Spectral Methods for Time-Dependent Problems*. Cambridge Monographs on Applied and Computational Mathematics **21**, Cambridge University Press, Cambrigde, UK

D. Gottlieb and J. S. Hesthaven, 2001, *Spectral Methods for Hyperbolic Problems*, J. Comput. Appl. Math. **128**(1-2), pp. 83-131.

V. Zharnitsky, E. Grenier, S. K. Turitsyn, C. K. R. T. Jones, and J. S. Hesthaven, 2000, *Ground States of Dispersion Managed NLS*, Phys. Rev. E. 62(5), 7358-7364.

J. S. Hesthaven, J. Juul Rasmussen, L. Berge and J. Wyller, 1997, *Numerical studies of localized wave fields govenered by the Raman-extended derivative nonlinear Schrodinger equation*, J. Phys. A: Math. Gen. **30**, 8207-8224.

J. Juul Rasmussen, J. P. Lynov, J. S. Hesthaven and G. G. Sutyrin, 1994, *Vortex Dynamics in Plasmas and Fluids*, Plasma Phys. Control. Fusion **36**, B193-B202.

- **5 Other significant publications**

J.S. Hesthaven and T. Warburton, 2008, *Nodal Discontinuous Galerkin Methods: Algorithms, Analysis, and Applications.* Springer Texts in Applied Mathematics **54**, Springer Verlag, New York. XIV.

D. Xiu and J.S. Hesthaven, 2005, High-Order Collocation Methods for Differential Equations with Random Inputs, SIAM J. Sci. Comput. 27, 1118-1139.

J. S. Hesthaven, 2003, *High-Order Accurate Methods in Time-Domain Computational Electromagnetics. A Review.* Advances in Imaging and Electron Physics **127**, pp. 53-127.

L. Wilcox, P. G. Dinesen, and J. S. Hesthaven, 2004, *Fast and Accurate Boundary Variation Method for Multilayered Diffraction Optics*, J. Opt. Soc. Ame. A **21**(5), 757-769.

S. Abarbanel, D. Gottlieb, and J. S. Hesthaven, 2002, *Long Time Behavior of the Perfectly Matched Layer Equations in Computational Electromagnetics*, J. Sci. Comput. **17**(1-4), 405

Synergistic Activities • Directs interdisciplinary research center at Brown, supporting the use of advanced computing technology in teaching, learning, and research across the university disciplines

- Taught numerous summer/winter schools and special courses.
- Editorial board member for 8 international journals.
- Organizer or Co-organizer of international conferences, e.g., ICOSAHOM'04; WAVES 2005.
- Reviews manuscripts for numerous journals and publishers. Reviews proposals for NSF(DMS) and have participated in NSF panel reviews.

Collaborators Within the Last 48 Months

S. Abarbanel (Tel Aviv, Israel); M. Carpenter (NASA LaRC, VA); C. Chauviere (Clairmont-Ferant, France); Q.Y. Chen (UMass Amherst, MA); S. Chun (CMU, PA); P. Diamessis (Cornell, NY); A. Ditkowski (Tel Aviv, Israel); K. Dridi (NKT, Denmark); J. A. Domaradzki (USC, CA); A. Engsig-Karup (DTU, Denmark); D. Gottlieb (Brown, RI); S. Gottlieb (UMass, MA); J. Grooss (DHI, Denmark); F. Giraldo (NRL, CA); H. Haddar (INRIA, France); G. Jacobs (SDSU, CA); S. M. Kaber (Paris VI, France); G. Karniadakis (Brown, RI); A. Kanevsky (Courant, NY); R. Kirby (Utah, UT); Y. Maday (Paris VI, France); C.-D. Munz (Stuttgart, G); L. Lurati (Brown, RI); L. Olson (UIUC, IL); T. Warburton (Rice, TX); L. Wilcox (UT Austin, TX) D. Xiu (Purdue, IL);

Graduate and Postgraduate Advisors

- **Thesis advisors** Profs. P.G. Thomsen and P. C. Hansen, Technical University of Denmark, and Drs. J.P. Lynov and J. Juul Rasmussen, Risø National Laboratory.
- **Postdoctoral advisor** Prof. D. Gottlieb, Division of Applied Mathematics, Brown University.

Thesis and Postdoctoral Advisees

- **Graduate Advisees** B. Yang (Cadence Inc); C. H. Teng (National University of Taiwan); A. Kanevsky (Courant); L. Wilcox (UT Austin); L. Lurati (Boeing Phantom); C. Q. Chen (UMass Amherst); S. Chun (CMU);
- **Postdoctoral Advisees** P. G. Dinesen (Kaleido Technology , DK); T. Warburton (Rice); C. Chauviere (Clairmont-Ferant, F); G. Jacobs (SDSU), L.Olson (UIUC), S. Lau (Brown), Y. Chen (Brown).

GEORGE Em KARNIADAKIS, Professor of Applied Mathematics

a. Professional Preparation

Ph.D., MIT, 1987; M.S., MIT, 1984; Postdoc, Stanford University, 1987-88; B.Sc., NTU, Athens (Greece), 1982.

b. Appointments

July 1996 - present, Professor, Applied Mathematics, Brown University.

Sept. 2000 - present, Visiting Professor/Senior Lecturer, Mechanical Engineering, MIT.

Fall quarter 2007: Visiting Professor, Peking University.

Jan. 1994 - June 1996, Associate Professor, Brown University.

Spring quarter 1993: Visiting Professor, Caltech.

Sept. 1988 - Dec. 1993: Assistant Professor, Princeton University.

c.i. Five Related Recent Publications

1. L. Grinberg and G.E. Karniadakis. "A Scalable Domain Decomposition Method for Ultra-Parallel Arterial Flow Simulations," Communications in Computational Physics, vol. 4, pp. 1151-1169, 2008.

2. S. Dong, J. Insley, N.T. Karonis, M. Papka, J. Binns and G.E. Karniadakis. "Simulating and visualizing the human arterial system on the TeraGrid," Future Generation Computer Systems, The International Journal of Grid Computing: Theory, Methods and Applications, vol. 22, pp. 1011-1017, 2006.

3. I. Pivkin, P. Richardson, and G.E. Karniadakis. "Blood flow velocity effects and role of activation delay time on growth and form of platelet thrombi," Proceedings of the National Academey of Sciences, vol. 103, pp. 17164-17169, 2006.

4. S. Dong, N.T. Karonis and G.E. Karniadakis. "Grid solutions for biological and physical cross-site simulations on the TeraGrid," In Proceedings of 20th IEEE International Parallel and Distributed Processing Symposium (IPDPS06), Rhodes Island, Greece, April 2006.

5. B. Boghosian, P. Coveney, S. Dong, L. Finn, S. Jha, G.E. Karniadakis and N.T. Karonis."Nektar, SPICE and Vortonics: Using Federated Grids for Large Scale Scientific Applications," Workshop on Challenges of Large Applications in Distributed Environments (CLADE), in conjunction with 15th International Symposium on High Performance Distributed Computing (HPDC-15), Paris, France, June 2006.

c.ii. Five Other Recent Publications

1. G.E. Karniadakis and R.M. Kirby, "Parallel Scientific Computing in C++ and MPI," Cambridge University Press, 2002.

2. G.E. Karniadakis and A. Beskok, "Micro Flows and Nanoflows: Fundamentals and Simulation," Springer, 2001; second expanded edition 2005.

3. G.E. Karniadakis and S.J. Sherwin, "Spectral/hp Element Methods for CFD," Oxford University Press, 1999; second expanded edition 2005.

4. S. Dong and G.E. Karniadakis, "Dual-level parallelism for high-order CFD methods," Parallel Computing, vol. 30(1), pp. 1-20, 2004. (Ten most downloaded articles in Parallel Computing).

5. Y. Du and G.E. Karniadakis, "Suppresing wall turbulence by means of a transverse traveling wave," Science, vol. 288, pp. 1230-1234, 2000.

d. Synergistic Activities: (•) Member of : EuroPhysiome (2006); NIH strategic planning group in computational biology (2006); WTEC panel to evaluate computational science in USA against the rest of the world (2007). (•) Served in many NSF supercomputing and Teragrid committees (a user since 1985). (•) Developed and maintained the code NEKTAR (freeware) used in Universities, national labs, and industry. (•) Work appeared on the covers of many scientific journals and other magazines (e.g. Physics Today, Scientific Computing & Automation, Parity, Phys. Rev. Lett); also in SCIENCE, and in Aerospace 2001, NCSA Access (three times). (•) Many of advisees hold tenure-track positions in diverse fields (Applied Math, Microfluidics, Computer Science, Bioengineering, Combustion)

e. Collaborators & Other Affilliations

Collaborators: S. Suresh, C. Crysostomidis, D. Yue and M. Triantafyllou (MIT); M. Gharib (Caltech); J.R. Madsen (Harvard Medical School); J. Georgiadis (UIUC); S. Sherwin (Imperial College); N. Karonis (NIU/Argonne National Labs); S. Dong (Purdue); M. Maxey, B. Caswell, C.-H. Su, D. Laidlaw & P. Richardson (Brown).

Advisors:Anthony T. Patera and Bora B. Mikic (MIT, Ph.D. thesis advisors). Parviz Moin and John Kim (Stanford/Nasa Ames, Post-doctoral advisors).

Graduate and Postdoctoral Advisees: Dr. P.F. Batcho (Los Alamos); • Dr. R.D. Henderson (Dream Works); • Dr. I.G. Giannakouros (ETH, Zurich); • Prof. S.J. Sherwin (Imperial College); • Prof. A. Beskok (Old Dominion University); • Dr. D.J. Newman; • Dr. C.H. Crawford (IBM); • Dr. B. Gervang; • Prof. L. Kaiktsis (NTUA); • Dr. D. Pathria; • Dr. D. Sidilkover (ICASE); • Dr. C. Quillen; • Dr. T. Matushima; • Dr. Ma Xia (Los Alamos); • Prof. T.C. Warburton (Rice University); • Dr. J. Trujillo; • Dr. I. Lomtev (Fidelity); • Dr. C. Evangelinos (MIT); • Dr. H. Marmanis; • Dr. Y. Du (Microsoft); • Prof. F. Liu (Taiwan); • Prof. R.M. Kirby (University of Utah); • Prof. D. Xiu (Purdue University); • Prof. D. Lucor (University of Paris, VI); • Prof. D. Liu (Louisisna Tech); • Dr. J. Xu (Argonne National Labs); • Dr. V. Symeonidis (MIT); • Dr. I. Pivkin (MIT); • Prof. Steven Dong (Purdue University); • Dr. X. Wan (Princeton University); • Dr. G. Lin (DOE/PNL); • Dr. Jasmine Foo (Kettering Cancer Center, NY).

ANDRIES VAN DAM, PH.D.

Thomas J. Watson, Jr., University Professor
Of Technology and Education, and
Professor of Computer Science
Brown University
Box 1910
Providence, RI 02912

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Fax: (401) 863-7657
Email: avd@cs.brown.edu

Education

B.S. Swarthmore College Engineering Sciences BS with honors, 1960
M.S. University of Pennsylvania Electrical Engineering, Moore School of Electrical Engineering, 1963
Ph.D. University of Pennsylvania Electrical Engineering, Moore School of Electrical Engineering, 1966

Professional Experience

Co-chair, Rhode Island Science and Technology Advisory Council, 2005-2006
Vice President for Research, Brown University, 2002-2006
Director, National Science Foundation Science & Technology Center for Computer Graphics and Scientific Visualization, 1995-1998
Visiting Scientific Associate, CERN, Geneva, Switzerland, 1980-1986
Chairman, Department of Computer Science, Brown University, 1979-1985
Professor of Computer Science, Brown University, 1979-
Professor of Computer Science and Applied Mathematics, Brown University, 1976-1979
Assistant, Associate Professor of Applied Mathematics, Brown University 1965-1976

Awards and Achievements and Professional Record

2007 Honorary Ph.D. from University of Waterloo in Canada
2005 AAAS (American Association for Advancement of Science) Fellow
2002 CRA Distinguished Service award and the Brown University Sheridan Teaching award
2000 Fellow of the American Academy of Arts and Sciences
1996 Inducted into the National Academy of Engineering
1996 Honorary Ph.D. from Swarthmore College
1995 Honorary Ph.D. from Darmstadt Technical University in Germany
1994 ACM Karl V. Karlstrom Outstanding Educator
1994 IEEE Fellow and an ACM Fellow
1991 ACM SIGGRAPH Steven A. Coons Award
1990 National Computer Graphics Association's Academic Award
1984 IEEE Centennial Medal
1974 Society for Information Display's Special Recognition Award

Research Interests

Professor van Dam's research has concerned computer graphics, hypermedia systems, post-WIMP user interfaces, including pen-centric computing, and educational software. He has been working for four decades on systems for creating and reading electronic books with interactive illustrations for use in teaching and research.

Synergistic Activities

In 1967, Professor van Dam co-founded ACM SICGRAPH which later became SIGGRAPH and from 1985 through 1987 was Chairman of the Computing Research Association. He has been Associate Editor of the "ACM Transactions on Graphics" (1981-1986), Editorial Board Member of "Computers and Graphics", Pergamon Press (1983 -1994), Advisory Editor, "Journal of Visual Languages and Computing", Academic Press (1989-1998), and Editorial Board Member of the "IEEE Transactions on Visualization and Computer Graphics", (1994-1998). He headed the Technical Advisory Board of the Fraunhofer Center for Research in Computer Graphics from 1994-2004, and was on the Technical Advisory Board for Microsoft Research (1992-2007).

Selected Publications (total > 100):

- "Immersive Electronic Books for Surgical Training." (with Greg Welch, Ruigang Yang, Sascha Becker, Adrian Ilie, Dan Russo, Jesse Funaro, Andrei State, Kok-Lim Low, Anselmo Lastra, Herman Towles, Bruce Cairns, M.D., Henry Fuchs) IEEE Multimedia, 12(3), pp. 22-35, July-September 2005.
- "Next-Generation Educational Software: Why We Need It and a Research Agenda for Getting It" (with Sascha Becker, and Rosemary Michelle Simpson). in Educause Review, March/April 2005, 40(2), pp. 26-43, 2005.
- "Grand Challenge 3. Provide a Teacher for Every Learner" in Grand Research Challenges in Information Systems. Anita Jones and William Wulf, editors, Computing Research Association, pp. 17-22, 2003.
- "User Interfaces: Disappearing, Dissolving, and Evolving," in Communications of the ACM 43(3) (2001).
- "Post-Wimp User Interfaces: the Human Connection" in Communications of the ACM 40(2) (1997). Frontiers of Human-Centered Computing, OnLine Communities and Virtual Environments, (Rae Earnshaw, Richard Guedj, Andries van Dam, and John Vince [Eds]), Springer Verlag, London, 2001, ISBN 1-85233-238-7.

Collaborators and Co-Editors
Rachel (Ben Shine) Becker, Laszlo Systems; Andrew S. Forsberg, Brown University; James Head, Brown University; Loring Holden, Brown University; David H. Laidlaw, Brown University; Jaron Lanier; Joseph J. LaViola, Jr., University of Central Florida; Chuanjun Li, Brown University; Richard May, Pacific Northwest National Laboratory; Tim Miller, Brown University; Laura Munroe, Los Alamos National Laboratory; Rosemary M. Simpson, Brown University; Mel Slater, University College London; Anne Spalter, Brown University; Jim Thomas, Pacific Northwest National Laboratory; David Yaron, Carnegie Mellon; Robert Zeleznik, Brown University

Graduate and Postdoctoral Advisor: Professor Josh Gray, Department of Computer and Information Science, University of Pennsylvania

Graduate student advisees and Postgraduate-Scholars in the past five years: Andrew Bragdon, Joseph LaViola, Dmitri Lemmerman, Chuanjun Li, Christopher Maloney, Dana Tenneson

Kenneth Breuer

Professor of Engineering
Division of Engineering, Box D
Brown University
Providence, RI 02912

Citizenship: United States
Tel: (401) 863-2870
Fax: (401) 863-9028
Email: kbreuer@brown.edu
Web: http://fluids.engin.brown.edu

Professional Preparation

Bachelor of Science (Sc.B)	Engineering (Concentrating in Fluids and Thermal Sciences) *Brown University*, 1978-1982
Masters of Science (M.S)	Dept. of Aeronautics and Astronautics, *Massachusetts Institute of Technology*, 1982-1984.
Doctorate (Ph.D.)	Department of Aeronautics and Astronautics, *Massachusetts Institute of Technology*, 1985-1988
Postdoctoral Fellow	Division of Applied Math., *Brown University* 1988-1990.

Professional Appointments

Professor	Division of Engineering, *Brown University*, 2006 - present
Associate Professor	Division of Engineering, *Brown University*, 1999-2006
Principal Res. Scientist,	Department of Aeronautics and Astronautics, *Massachusetts Institute of Technology*, 1998-1999
Associate Professor,	Department of Aeronautics and Astronautics, *Massachusetts Institute of Technology*, 1996-1998
Assistant Professor,	Department of Aeronautics and Astronautics, *Massachusetts Institute of Technology*, 1990-1996

Selected recent research publications (relevant to this proposal)

1. Kim, M., Bird, J.C., Van Parys, A.J., Breuer, K.S. & Powers, T.R. "A macroscopic scale model of bacterial flagellar bundling." *PNAS.*, **100**(26). pp. 15481-15485. 2003.
2. Kim, M. & Breuer, K.S. "Enhanced diffusion due to motile bacteria." *Physics of Fluids*, **16**(9), pp. 78-81. 2004.
3. Jay,G.D, Torres, J.R, Warman, M. L, Laderer, M.C. and Breuer, K.S. " The role of lubricin in the mechanical behavior of synovial fluid" *PNAS.* **104** (15) pp. 61946-199, April 2007.
4. Kim, M.J. and Breuer, K.S. "Controlled Mixing in Microfluidic Systems Using Bacterial Chemotaxis." *Analytical Chemistry* **79**. pp. 955-959. 2007.
5. Huang, P. and Breuer, K.S. "Direct measurement of anisotropic near-wall hindered diffusion using total internal reflection velocimetry" *Phys Rev. E.* **76**, 046307. 2007.
6. Guasto, J & Breuer, K.S. "Simultaneous, ensemble-averaged measurement of near-wall temperature and velocity in steady micro-flows using single quantum dot tracking" *Experiments in Fluids* DOI 10.1007/s00348-008-0471-y (2008)
7. Qian, B, Powers, T.R. and Breuer, K.S. "Shape transition and propulsive force of an elastic rotating in a viscous fluid" *Phys. Rev. Lett*. **100**, 078101 (2008).

8. Song, A, Tian, X, Israeli, E, Galvao, R, Bishop, K, Swartz, S and Breuer, K. "Aeromechanics of Membrane Wings, with Impications forAnimal Flight". *AIAA Journal* **46** (8) pp2096-2196. 2008. doi: 10.2514/1.36694
9. Swartz, SM, Breuer, KS and Willis, DJ. "Aeromechanics in aeroecology:flight biology in the aerosphere". *Integrative and Comparative Biology*. **48** (1) pp. 85-98 2008. doi:10.1093/icb/icn054. June 2008.
10. Daniel K. Riskin; David J Willis; Jose Iriarte-Diaz; Tyson L Hedrick; Mykhaylo Kostandov; Jian Chen; David H Laidlaw; Kenneth S Breuer; Sharon M Swartz. "Quantifying the complexity of bat wing kinematics". *J Theo. Bio* **254** pp.604-615. 2008.

Synergistic Activities:

- **Active Research Programs:** Bacterial Mechanics, Bat flight mechanics. Microscale fluid mechanics, Active control of Turbulence, Research Group 2 Post Docs, 7 grad students 4 undergraduate students.
- **Research Expertise:** Fluid Mechanics, experimental methods in fluid mechanics. Particle Image Velocimetry, Microscale fluid mechanics, optical diagnostics for fluid measurements. Scale testing in biological fluid mechanics. Wind tunnel measurements,
- **Renewable Energy Activities:** Research program on energy generation using nanotechnology, Developed and co-teach course in Sustainable Energy Technologies, Advisor for Solar House design, Consulting experience with Wind and Water power Energy system developers.
- **Activities:** Founder and Chair ASME *Microfluidics Symposium* 2000, 2001 and Chairman of *ASME Micro and Nanofluidics Technical Committeee (2004-6)*. Co-Chairman of ASME NanoInstitute committee on nanoscale phenomena. Associate Editor: *Journal of Fluids (2003-06) Engineering, Microfluidics and Nanofluidics (2005-present)*
- **Educational and Outreach:** Co-author: *Multimedia Fluid Mechanics* (Cambridge Univ. Press), *A* Co-Editor: *Gallery of Fluid* Motion (Camb. Univ. Press), Featured on several educational TV features (*Discovery Channel, PBS-NOVA, New Scientist, Science Daily, Reuters*).

Collaboration and supervision (past three years):

Collaborators: Howard Berg (*Harvard*), Greg Huber (*UConn*) Thomas Powers (*Brown*). Sharon Swartz (*Brown*), George Karniadakis (*Brown*), George Homsy (*University of California-Santa Barbara*), Michael Lawrence (*UVa*), Jaime Peraire (*MIT*), Mark Drela (*MIT*), Marc Fermigier (*ESPCI*), Cynthia Moss (UMd)
Graduate and Post Doctoral Advisors: Marten Landahl (*Deceased*), Sheila Widnall (*MIT*), Joseph Haritonidis (*Ohio State University*), Lawrence Sirovich (*Mt. Sinai School of Medicine*)
Thesis Advisor and Postgraduate-Scholar Sponsor*: Ph.D.:* Qian Bian, Arnold Song, Charles Peguero, Joe Bahlman, Shawn Kitchner, Rye Waldman, Jeff Guasto (*Haverford*), MinJun Kim (*Drexel*), Peter Huang (*SUNY Binghampton*) *Postdocs:* Tatjana Hubel, Daniel Riskin, DavidWilis (U.Mass Lowell) (Total theses supervised since 1990: 15 MS, 11 PhD)

John Cayley

Visiting Professor
Literary Arts Program
Brown University
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Education

1978 BA Hons, Oriental Studies (Chinese Language and Civilization), Durham University, Durham, UK

Experience

2007-present Visiting Professor, Literary Arts Department, Brown University
2000-2007 Director/Share-holder, Hanshan Tang Books Ltd., London
1992-2000 Self-employed as Publisher, Bookseller and Consultant
1990-1992 Managing Editor, Bamboo Publishing Ltd., London
1988-present Founder/Publisher of the Wellsweep Press (literary translation from Chinese)
1988-2000 Hanshan Tang Books (specialist booksellers, East Asian art)
1986-1988 Curator, British Library, Oriental Collections, Chinese Section
1984-1986 Research Associate, University of Newcastle, UK, Dept. of Politics (research database of Chinese Provincial Leaders)
1982-1984 Computing Instructor and Training Manager, ICP Youth Training Scheme, Durham, UK

Selected Publications

- 'Lens: The Practice and Poetics of Writing in Immersive VR: A Case Study with Maquette.' Leonardo Electronic Almanac 14.5-6 (2006)
- Lens and Torus, Two Cave-based pieces initiated at Brown University, 2004.
- Translation, Interlingual development of ambient poetics in digital multimedia, 2004
- Overboard, An example of ambient poetics in digital multimedia, 2003

Other Publications

- 'Screen Writing: A Practice-Based, Eurorelative Introduction to Electronic Literature and Poetics.' *Third Text: Writing Europe Special Issue* 21.5 (88) (2007): 603-09.
- 'Lens: The Practice and Poetics of Writing in Immersive VR: A Case Study with Maquette.' *Leonardo Electronic Almanac* 14.5-6 (2006): [website, http://leoalmanac.org/journal/vol_14/lea_v14_n05-06/jcayley.asp].
- 'Hallucination and Coherence.' *Positions* 10.3 (2002): 773-84.
- 'A Stranger to Yourself: Ways of Becoming an Other. An Interview/Discussion with Yang Lian.' *New Formations* 40 (2000): 15-29.
- 'Beyond Codexspace: Potentialities of Literary Cybertext.' *Visible Language* 30.2 (1996): 164-83.
- 'Pressing The "Reveal Code" Key.' *EJournal* 6.1 (1996): [Internet based, accessible: http://www.hanover.edu/philos/ejournal/archive/ej-6-1.txt].
- 'Birds and Stars: Tagore's influence on Bing Xin's early poetry', *Renditions*, 32 (Autumn 1989) pp. 118-123
- *Book Unbound. Indra's Net VI* in *Postmodern Culture* 7.3 (1997) [website, http://muse.jhu.edu/journals/pmc/v007/].
- '"To keep them from falling" - on some of the Translator's Responsibilities' *Renditions* (Hong Kong, Chinese Univ., Research Centre for Translation) 21 & 22 (Spring and Autumn 1984) 331-348.

- 'The Literal Image: "Illustrations" in the Cantos,' *Paideuma*, 14.2&3 (Fall & Winter 1985) 227-251 (also to be included in a volume from the National Poetry Foundation's 'Man and Poet' series devoted to Pound, still NYP).
- 'CH'ENG, or Sincerity', *Paideuma* (a journal devoted to Ezra Pound scholarship, University of Maine at Orono), 13.2 (Fall 1984) 201-209.

Synergistic Activities

Collaborators and Other Affiliations
Collaborators and Co-Editors: Robert Coover, Adjunct Professor, Department of Literary Arts, Brown University

Advisees: Aya Karpinska, Jessica Laser, Miya Perry, Jeremy Ashkenas

NSF Biographical Sketch

(Maximum of 2 pages)

Name: Stephen Correia, PhD Organization: Brown Medical School
Dept: Psychiatry & Human Behavior Location: Veterans Affairs Medical Ctr

Professional Preparation

(A list of the individual's undergraduate and graduate education and postdoctoral training as indicated below)

Institution	Major	Degree	Year
University of RI	Psychology	BA	1982
University of RI	Clinical Psychology	PhD	2001
Brown University	Fellowship	N/A	2001-2003
Brown University	Fellowship (T32 reseach)	N/A	2003-2005

Appointments

2005-present Neuropsychologist, Veterans Affairs Medical Center, Providence RI
2005-present Assistant Professor, Dept. of Psychiatry & Human Behavior, Warren Alpert Medical School of Brown University.
2003-2005 Dementia Research Fellow (T32), Department of Psychiatry & Human Behavior, Brown Medical School
2002-2003 Research Neuropsychologist, Butler Hospital, Providence, RI
2000-2002 Post-Doctoral Neuropsychology Fellowship, Butler Hospital, Brown Medical School
1999-2000 Pre-Doctoral Neuropsychology Internship, Malcolm Randall VA Medical Center, Gainesville, FL

Publications *(10 maximum)*

1. MacLean A, Correia S, Woods R, Stopa E, Cortez S, Alderson L, Salloway S. Spontaneous lobar hemorrhage in CADASIL. *J Neurology Neurosurgery and Psychiatry*, 2005.
2. Grant JE, Correia S, Brennan-Krohn T, Laidlaw D. (2006). White matter integrity in kleptomania: A pilot study. Psychiatry Research, 147(2-3), 233-7.
3. Malloy P, Correia S., Stebbins G., & Laidlaw DH. (2007) Neuroimaging of white matter: A review of methods and neuropsychological correlates in aging. Invited review paper, Archives of Clinical Neuropsychology. The Clinical Neuropsychologist , 21(1) 73-109.
4. Salloway S, Correia S, Richarson S. (2007). Key Lessons Learned from Short-Term Treatment Trials of Cholinesterase Inhibitors for Amnestic MCI. International Psychogeriatrics, June 28, 1-7
5. Laidlaw DH, Lee SY, Correia S, Tate DF, Paul RH, Zhang S, Salloway SP, & Malloy PF. (2006). Quantitative TOI Metrics for White Matter Integrity Based on Diffusion Tensor MRI Data. Views Radiology 8(4) 21-23.
6. Grant JE, Correia S, Brennan-Krohn T, Malloy PF, Schulz C. (2007) White matter integrity in borderline personality disorder with self-injurious behavior: a pilot study. Journal of Neuropsychiatry and Clinical Neurosciences 19(4):383-90.

7. Zhang S, Correia S, Laidlaw DH (2008) Identifying white-matter fiber bundles in DTI data using an automated proximity-based fiber-clustering method" IEEE Transactions on Visualization and Computer Graphics 14(5) 1044-1505.
8. Chen W., Zhang S., Correia S, Ebert D. Abstractive Representation and Exploration of Hierarchically Clustered Diffusion Tensor Fiber Tracts. Computer Graphics Forum (Special Issue of Eurographics/IEEEVGTC Symposium on Visualization 2008), 27(3) (in press).
9. Salloway, S. & Correia, S. One hundred years of Alzheimer's disease: Time to improve diagnosis and treatment in primary care. Cleveland Clinic Journal of Medicine (in press).
10. Correia S, Lee S, Voorn T, Tate D, Paul R, Zhang S, Salloway S., Malloy P, Laidlaw DH. Quantitative Tractography Metrics of White Matter Integrity in Diffusion-Tensor MRI Neuroimage, 42 568-81.

Synergistic Activities *(5 max)*

2008-present	Imaging Core Executive Committee, Dominantly Inherited Alzheimer's Disease (DIAN) Study; Washington University, St. Louis (coordinating center); Butler Hospital Memory and Aging Program.
2008- present	MRF Educational Training and Advisory Committee MRI Research Facility Brown University
2006-present	Director, Neuropsychology Grant Writing Seminar, Brown University
2005-2007	International Society for Vascular Behavioural and Cognitive Disorders, Student representative to Scientific Committee
2003-2004	Clinical trails consultant for protocol design; Sention Inc.: A Randomized, Double-Blind, Placebo-Controlled, Parallel-Group Study to Assess the Safety, Tolerability, and Efficacy of Titration and Treatment with C105 in Subjects with Mild Cognitive Impairment (MCI)
2000-present	Research supervisor for independent research fellowships, Brown University undergraduate, graduate, and medical school students.

Collaborators & Other Affiliations

Laidlaw, David, Ph.D.; Brown University
Malloy, Paul, Ph.D.; Brown University
Salloway, Stephen, M.D.; Brown University
Zhang, Song, Ph.D., Mississippi State University
Ronald Cohen, Ph.D., Brown University
Benjamin Greenberg, M.D., Brown University
Robert Paul, Ph.D., University of Missouri
Linda Resnik, Ph.D., Brown University
David Faust, Ph.D., University of Rhode Island
Leigh Hochberg, M.D., Brown University
Albert Lo, M.D., Brown University

(b) Graduate and Postdoctoral Advisors.

Faust, David, Ph.D.; University of Rhode Island
Salloway, Stephen, M.D.; Brown Medical School
Malloy, Paul, Ph.D.; Brown Medical School

(c) Thesis Advisor and Postgraduate-Scholar Sponsor.

David Faust, Ph.D.
Robert Swift, M.D.

Biographical Sketch

Robbert Creton

(a) Professional Preparation

Univertity of Utrecht, Netherlands	Biology	B.S.	1990
Univertity of Utrecht, Netherlands	Developmental Biology	Ph.D.	1994
Marine Biological Laboratory, Woods Hole, MA	Developmental Biology	1995 -	1999

(b) Appointments

Assistant Professor of Medical Science (Research) 2002 - present
Department of Molecular Biology, Cell Biology, and Biochemistry
Brown University

Director of the Leduc Bioimaging Facility 2002 - present
Division of Biology and Medicine
Brown University

Investigator 1999 - 2002
OB-GYN Department
Women & Infants Hospital of Rhode Island

(c) Five publications most closely related to the proposed project

Kreiling J.A., Balantac Z.L, Crawford A., Ren Y., Toure J., Zchut S., Kochilas L., Creton R. (2008). Suppression of the endoplasmic reticulum calcium pump during zebrafish gastrulation affects left-right asymmetry of the heart and brain. Mech Dev 125, 396-410.

Kreiling J.A., Prabhat, Williams G., Creton, R. (2007). Analysis of Kupffer's vesicle in zebrafish embryos using a cave automated virtual environment. Dev Dyn. 236,1963-1969.

Creton R. (2004). The calcium pump of the endoplasmic reticulum plays a role in midline signaling during early zebrafish development. Developmental Brain Res. 151, 33-41.

Creton R., Kreiling J.A., and Jaffe L.F. (1999). Calcium imaging with chemiluminescence. Microsc. Res. Tech., 46, 390-397.

Creton R., Speksnijder J.E. and Jaffe L.F. (1998). Patterns of free calcium in the zebrafish embryo. J. Cell Science 111, 1613-1622. http://jcs.biologists.org/cgi/reprint/111/12/1613

Five other significant publications

Creton, R. (2009). Automated analysis of behavior in zebrafish larvae. Submitted for publication.

Kreiling J.A., Creton R, Reinisch C. (2007). Early embryonic exposure to polychlorinated biphenyls disrupts heat-shock protein 70 cognate expression in zebrafish. J Toxicol Environ Health A. 70, 1005-1013.

Wong JL, Creton R, and Wessel GM (2004). The oxidative burst at fertilization is dependent upon activation of the dual oxidase Udx1. Dev. Cell 7, 801-814.

Creton R. and Jaffe L.F. (2001). Chemiluminescence microscopy as a tool in biomedical research. BioTechniques 31, 1098-1105.

Creton R., Kreiling J.A., and Jaffe L.F. (2000). Presence and roles of calcium gradients along the dorsal-ventral axis in Drosophila embryos. Dev. Biol. 217, 375-385.

(d) Synergistic Activities

1. Expanded the imaging capabilities in the Bioimaging Facility, a core facility with microscopes and image analysis systems, which now serves more than 200 users.

2. Development of a course in Bioimaging (Bio 206), and development of a digital trainer in microscopy (digital TIM) to assist with instruction on the microscopes.

3. Development of a non-invasive non-fluorescent imaging technique to visualize heart laterality in zebrafish embryos and development of an automated imaging system for studying behavior in zebrafish larvae.

4. Trainer in the MCB Graduate Program and a mentor in the Masters Program in Biomedical Engineering.

5. Tours and demos in the Bioimaging Facility for high school students.

(e) Collaborators & Other Affiliations

Collaborators & Co-Editors in preceding 48 months

Balantac, Z.L., Brown University
Colwill, R., Brown University.
Crawford, A., Brown University
Kreiling, J.A., Marine Biological Laboratory, Woods Hole.
Kochilas, L.K., Rhode Island Hospital.
Prabhat, Brown University
Reinisch, C., Marine Biological Laboratory, Woods Hole.
Ren, Y., Rhode Island Hospital
Toure, J., Brown University
Wessel, G.M., Brown University
Williams, G., Brown University
Wong, J.L., Brown University
Zchut, S., Rhode Island Hospital.

Graduate and Postdoctoral Advisors

Dohmen M.R., University of Utrecht, Netherlands (graduate advisor)
Jaffe, L.F., Marine Biological Laboratory, Woods Hole (postdoctoral advisor)

Thesis Advisor and Postgraduate-Scholar Sponsor

Jamal Toure, Brown University

Fritz Drury

a. Professional Preparation

BA 1977 Stanford University
MFA 1981 Yale University School of Art

b. Appointments

Rhode Island School of Design, Providence RI
Professor of Illustration, June 2003-present
Department Head, Illustration 2000-2003
Associate Professor of Illustration and Foundation Studies, 1997-2003.
Adjunct Professor of Illustration and Painting 1981-1997.

c. Publications

Drawing Structure and Vision , textbook on drawing technique and tradition, Fritz Drury and Joanne Stryker, anticipated publication, September 2004, Prentice Hall, Upper Saddle River NJ.

Applying the Lessons of Visual Art to the Study of the Brain: abstract for presentation at Winter Conference on Brain Research, January 2004, with Profs David Laidlaw, David Kremers, Russell Jacobs, Arthur Toga.

Designer-critiqued Comparison Of 2D Vector Visualization Methods: A pilot study. In SIGGRAPH 2003 Sketches and Applications. IEEE, 2003. Cullen Jackson, Daniel Acevedo, David H. Laidlaw, Fritz Drury, Eileen Vote, and Daniel Keefe.

New Paintings, Project Room, The Painting Center, NYC October 2002

177th Annual Invitational, National Academy of Design, NYC May 2002

Solo Show, AAA Gallery, NYC, November 1998.
Review in Art in America July 1999, by Nancy Grimes.

Solo Show, "Bedtime Stories", Nancy Moore Gallery, NYC, May, 1997.

Solo Show, Black and Greenberg Gallery, NYC, April 1995.

Solo Show, "Nature", 55 Mercer Gallery, NYC, October 1993.
Review in Art in America, June 1994, by Eleanor Heartney.

d. Synergistic Activities

January 2004, Presentation at Winter Conference on Brain Research, Natural Media and Artistic Process in Scientific Visualization (within the group presentation: Applying Lessons of Visual Art to the study of the Brain).

March-May 2003- advisor to study by Daniel Acevedo and Colin Jackson on the design Visualization icons in relation to perceptual psychology.

September-December 2002, co-taught Interdisciplinary Scientific Visualization at Brown University with Professor David Laidlaw, studying collaboration between artists and scientists in the design of immersive, interactive scientific visualizations.

January- May 2003-Participant in interdisciplinary discussions between Brown University scientists and artists and designers from Rhode Island School of Design on the feasibility of collaborative work on visualization projects.

e. Collaborators and Other Affiliations

(i) Collaborators: Professor David Laidlaw, Department of Computer Science, Brown University, Professor Peter Richardson, Department of Engineering, Brown University, Professor Russell E. Jacobs, California Institute of Technology, Professor Arthur Toga, UCLA School of Medicine, David Kremers, California Institute of Technology, Department of Biology, Artist in Residence, Daniel Keefe, Department of Computer Science, Brown University, Daniel Acevedo, Department of Computer Science, Brown University, Cullen Jackson, Department of Computer Science, Brown University

(ii) Graduate Advisors: Professor William Bailey (emeritus) Yale School of Art, Professor Bernard Chaet (emeritus) Yale School of Art

Biographical Sketch: James W. Head, III

(i) Professional Preparation

Washington and Lee University	Geological Sciences	B.S. 1964
Brown University	Geological Sciences	Ph.D. 1969

(ii) Appointments

Brown University 1973-Present
(Louis & Elizabeth Scherck Distinguished Professor: 1995-Present; Professor: 1980-Present; Associate Professor: 1975-1980; Associate Professor-Research: 1974-1975; Assistant Professor-Research: 1973-1974)

Lunar Science Institute, Houston, Texas 1973-1974
Interim Director of Institute involved in scientific studies of lunar samples and experimental data obtained during lunar investigations.

Bellcomm, Inc., Washington, DC 1968-1972
Systems Analysis Branch of the National Aeronautics and Space Administration Headquarters. Studies relating to the Apollo Lunar Exploration Program.

(iii) Selected Publications

Forsberg, A., Prabhat, G. Haley, A. Bragdon, J. Levy, C. Fassett, D. Shean, J. Head, S. Milkovich and M. Duchaineau (2006) ADVISER: Immersive Field Work for Planetary Geoscientists, *IEEE CG&A special issue on Exploring GeoVisualization* 26:4, 46-54.

Head, J. W. (2001) Mars: Evidence for geologically recent advance of the south polar cap, *Journal of Geophysical Research, 106, E5*, 10075-10085.

Head, J. W., J. F. Mustard, M. A. Kreslavsky, R. E. Milliken and D. R. Marchant (2003) Recent ice ages on Mars, *Nature*, 4*26*, 797-802.

Head, J. W. and D. Marchant (2003) Cold-based mountain glaciers on Mars: Western Arsia Mons, *Geology,* 31:7, 641-644.

Head, J. W., A. van Dam, S. Fulcomer, A. Forsberg, Prabhat, G. Rosser and S. Milkovich (2005) Advanced Visualization in Solar System Exploration and Research (ADVISER): Immersive Scientific Visualization Applied to Mars Research and Exploration submitted to *Photogrammetric Engineering and Remote Sensing* Special Issue on Mars Mapping, 71:10, 1219-1225.

Head, J. W., L. Wilson, J. Dickson and G. Neukum (2006) The Huygens-Hellas Giant Dike System on Mars: Implications for Late Noachian-Early Hesperian Volcanic Resurfacing and Climatic Evolution, *Geology* 34 (4), 285-288.

Kreslavsky, M. A.; Head, J. W. (2002) Mars: Nature and evolution of young latitude-dependent water-ice-rich mantle. *Geophysical Research Letters*, *29*, No. 15, 10.1029/2002GL015392.

Head, J. W., C. R. Chapman, D. L. Domingue, S. E. Hawkins, W. E. McClintock, S. L. Murchie, L. M. Prockter, M. S. Robinson, R. G. Strom, T. R. Watters (2007) The geology of Mercury: The view prior to the MESSENGER Mission, *Space Sci. Rev. 131*:41-84.

(iv) Synergistic Activities

a) Co-convenor of the Brown University/Vernadsky Institute Microsymposia. Begun during the Cold War era, the Brown/Vernadsky symposia have been convened in the US and USSR/Russia, and provide a semiannual forum for Russian, European and American scientists to discuss and collaborate on research efforts, 1985 – present.

b) Organizer: Jet Propulsion Laboratory Mission Design Workshop; co-operative mission design involving undergraduate and graduate students and staff from Brown and several other universities with JPL scientists and engineers, Summer 1996-2005.
c) Co-teacher of a Brown Univ. engineering group independent study project on Policy and Design of Large Space Missions.
d) Consultant: "The Photography of Space Exploration," Grey Art Gallery and Study Center, New York University. Chief Elected Officer: Planetary Geoscience subdivisions of the AGU and GSA. Review panel chair and participant for numerous review panels.
e) Co-Investigator and geologist for the following recent scientific teams: Mars Global Surveyor/Mars Orbiter Laser Altimeter; Galileo Imaging Team; Mars Express High Resolution Stereo Camera (MEx HRSC) Team; Mercury: Surface, Space Environment, Geochemistry, and Ranging (MESSENGER) Team; Moon Mineralogy Mapper (M^3).

(v) Collaborators & Other Affiliations

a) Collaborators and Co-Editors: Coauthors on abstracts, papers, and proposals are numerous but include: A. T. Basilevsky, Vernadsky Inst., RAS, Moscow; M. A. Ivanov, Vernadsky Inst., RAS, Moscow; M. A. Kreslavsky, UC-Santa Cruz; David Marchant, Boston University; Lionel Wilson, Lancaster Univ., U.K.

b) Graduate Advisors: Leo F. LaPorte, Brown University, UC-Santa Barbara.
Thomas A. Mutch, Brown University (d. 1980).

c) Thesis Advisor and Postgraduate-Scholar Sponsor:
Undergraduate Thesis Advisor:
Jiganesh Patel, 1998.
Lillian Ostrach, 2007.

Masters Degrees Supervised (last 10 years):
Emily Stewart, 2000, Planetary Society.
Brian Kortz, 2001, gov. consultant.
Bradley Thomson, 2001, Applied Physics Lab, MD.
Benjamin Webb, 2002, CSM.
Karen Jager, 2002, instructor, Community College of RI.
Elizabeth Fuller, 2003, unk
Shawn McColley, 2005, Cold Regions Research and Engineering Lab.
Rebecca Parsons, 2005, UC-Santa Cruz.
Joseph Levy, 2006, continuing at Brown.
David Shean, 2006, Boston University.
Seth Kadish, Laura Kerber, Samuel Schon, 2008, all continuing at Brown.
Lillian Ostrach, 2008, Arizona State University.

Ph.D Degrees Supervised (within previous 10 years):
Cathy Weitz, 1998, NASA Headquarters
R. Aileen Yingst, 1998, University of Wisconsin at Green Bay
Louise Prockter, 1999, Johns Hopkins University
Geoffrey Collins, 2000, Wheaton College, MA
Nicole Spaun, 2001, FBI
Kathryn Fishbaugh, 2004, ISSI
Patrick Russell, 2005, Univ. of Berne
Sarah Milkovich, 2005, JPL
Gerald Patterson, 2007, Applied Physics Lab, MD
Caleb Fassett, 2008, Postdoctoral Fellow, Brown University.

SORIN C. ISTRAIL

a. PROFESSIONAL PREPARATION

Al. I. Cuza University, Department of Computer Science, Romania B.S. 1975
University of Bucharest, Department of Computer Science, Romania Ph.D. 1979

b. APPOINTMENTS

2006-present *Julie Nguyen Brown Professor of Computational and Mathematical Sciences,* Brown University
2006-present *Director, Center for Computational Molecular Biology*, Brown University
2005-present *Professor of Computer Science*, Brown University
2004-present *Visiting Associate, Division of Biology,* California Institute of Technology
2003-2005 *Applied Biosystems Science Fellow,* Applied Biosystems
2002-present *Adjunct Professor of Biochemistry and Molecular Biology*, Medical School, George Washington University
2002-2005 *Senior Director and Head of Informatics Research Group,* Applied Biosystems/ Celera Genomics
2001-2002 *Co-Leader with Gene Myers of the Informatics Research Group*, Celera Genomics
2000-2001 *Senior Director*, *Informatics Research Group*, Celera Genomics
1998-2000 *Adjunct Associate Professor of Biology*, University of New Mexico
1998-2000 *Principal Senior Member of the Technical Staff,* Sandia National Laboratories
1994-1998 *Senior Member of the Technical Staff*, Sandia National Laboratories
1993-2000 *Project Leader*, DOE MICS Computational Biology Project, Sandia National Laboratories
1992-1994 *Computational Scientist*, Sandia National Laboratories
1984-1992 *Visiting Scientist*, Massachusetts Institute of Technology
1984-1992 *Assistant Professor*, Wesleyan University
1979-1983 *Researcher, Institute of Mathematics*, Al. I. Cuza University, Romania

c. PUBLICATIONS

Five publications most closely related to the proposal

1. M. Samanta, W. Tongprasit, S. Istrail, A. Cameron. Q. Tu, E. Davidson, V. Stolc, The transcriptome of the sea urchin embryo, *Science*, vol. 314, pp. 960-962, 2006

2. S. Istrail, G. Sutton, L. Florea, A . Halpern, C. Mobarry, R. Lippert, B. Walenz, H. Shatkay I. Dew, J. Miller, M. Flanigan, N. Edwards, R. Bolanos, D. Fasulo, B. Halldorsson, S. Hannenhalli, R. Turner, S. Yooseph, F. Lu, D.R. Nusskern, B.C. Shue, X.H. Zheng, F. Zhong, A.L. Delcher, D.H. Huson, s.A. Kravitz, L. Mouchard, K. Reinert, K.A. Remington, A. Clark, M. Waterman, E. Eichler, M. Adams, M. Hunkapiller, E. Myers, C. Venter, Whole genome shotgun assembly and comparison of human genome assemblies, *Proceedings of the National Academy of Sciences* 101, pp. 1916-21, 2004

3. A. Caprara, R. Carr, S. Istrail, G. Lancia, and B. Walenz, 1001 Optimal PDB Structure Alignments: Integer Programming Methods for Finding the Maximum Contact Map Overlap, *Journal of Computational Biology* vol 11, No. 1, pp 27-52, 2004

4. Schwartz, R., S. Istrail, J. King, Frequencies of amino-acid strings in globular proteins sequences indicate suppression of blocks of consecutive hydrophobic residues, *Protein Science* 10: 1023-1031, 2001

5. D. Goldman, S. Istrail, C. Papadimitriou, Algorithmic Aspects of Protein Structure Similarity, *Proceedings of the IEEE Symposium on Foundations of Computer Science* (FOCS99), IEEE Computer Society Press, October 1999

Other Publications

6. S. Istrail, R. Schwartz, J. King, Lattice Simulations of Aggregation Funnels of Protein Folding, *Journal of Computational Biology*, vol. 6, no. 2, 1999

7. W. E. Hart, S. Istrail, Fast Protein Folding in the Hydrophobic-Hydrophilic Model Within Three-eighths of Optimal (Extended Abstract), *Proceedings of 27th Annual ACM Symposium on Theory of Computation* (STOC95), ACM Press,
pp. 157-168, 1995

d. SYNERGISTIC ACTIVITIES

- DOE INCITE FY 2008 Panel
- National Science Foundation, Data-Intensive Computing Panel, Cluster Exploratory Program, 2008
- IMA Workshop on Protein Folding: Organizers--Ken Dill, Sorin Istrail, and Michael Levitt
- Brown University IPP/CCMB Symposium "The Genome and the Computational Sciences: The Next Paradigms" Symposium Chair—Sorin Istrail

e. COLLABOARATORS & OTHER AFFILIATIONS

J. Abu-Threideh, M.D. Adams, D. Allen, P. Amanatides, R. M. Ballew, J. Baxendale, E. Beasley, K. Biddick, L. Blick, R. Bolanos, V. Bonazzi, R. Brandon S. Broder, M. Caminha, M. Cargill, J. Carnes-Stine, R. Carr, P. Caulk I. Chandramouliswaran, R. Charlab, K. Chaturvedi, L. Chen, Y-H. Chiang, A. G. Clark, M. Coyne, C. Dahlke, E. Davidson, A. Delcher, Z. Deng, A. Deslattes Mays, I. Dew, V. Di Francesco, E. E. Eichler, C. A. Evans, D. Fasulo, M. Flanigan, L. Florea, G. L. Gabor Miklos, J. D. Gocayne, A. Halpern, S. Hannenhalli, W. Hart, R. A. Holt, M. Hunkapiller, D. H. Huson, C. Kodira, S. Kravitz, F. Lam, G. Lancia, A. J. Levine, S. Levy, P. Li, V. A. McKusick, J. Miller, C. Mobarry, R. J. Mural, E. W. Myers, J. Nadeau, C. Nelson, K. Reinert, K. Remington, R. J. Roberts, S. Salzberg, R. Schwartz, W. Shao, B. Shue M. Simon, M. Skupski, C. Slayman, H. O. Smith, G. Subramanian, J. Sun, G.G. Sutton, R. Tarpine, P. D. Thomas, R. Turner, J. C. Venter, A. Wang, J. Wang, X. Wang, Z. Y. Wang, M. S. Waterman, M-H. Wei, R. Wides, J. R. Wortman, C. Xiao, C. Yan, M. Yandell, A. Yao, J. Ye, J. Yewdell, S. Yooseph, M. Zhan, H. Zhang, J. Zhang, Q. Zhang, W. Zhang, Q. Zhao X. H. Zheng, and N. Zinder.

Biographical Sketch, Mark A. Johnson

(a) Professional Preparation

Wake Forest University	Biology	B.S. 1993
Michigan State University	Microbiology & Cellular & Molecular Biology	Ph.D. 2000
The University of Chicago	HHMI/Molecular Genetics and Cell Biology	2000-2004

(b) Appointments

9/01/04 – present	Assistant Professor of Biology, Department of Molecular Biology, Cell Biology, and Biochemistry, Brown University
2000-2004	Postdoctoral Fellow with Dr. Daphne Preuss, HHMI/Molecular Genetics and Cell Biology, The University of Chicago

(c) Publications

Relevant Publications:

Von Besser K, Frank A, Johnson MA*, and Preuss D. (2006) Arabidopsis *HAP2* is a sperm-specific gene required for pollen tube guidance and essential for fertilization. *Development*.133(23):4761-9. *corresponding author (http://dev.biologists.org/cgi/content/full/133/23/4761)

Johnson MA, and Lord, E. Extracellular Guidance Cues and Intracellular Signaling Pathways that Direct Pollen Tube Growth. (2006) In, "The Pollen Tube: A Cellular and Molecular Perspective" Rui Malhó, editor. Plant Cell Monographs, Springer Berlin / Heidelberg pp. 223 – 242.

Johnson MA, von Besser K, Zhou Q, Smith E, Aux G, Patton D, Levin J, Preuss D (2004) *Arabidopsis hapless* mutations define essential gametophyte functions. *Genetics* 168 (2):971-82. (http://www.genetics.org/cgi/content/full/168/2/971)

Johnson MA and Preuss D (2002). Plotting a course: Multiple signals guide pollen tubes to their targets. *Developmental Cell*. 2:273-281. (http://www.developmentalcell.com/content/article/abstract?uid=PIIS1534580702001302)

Other Publications:

Chiba Y, Johnson MA, Lidder, Vogel JT, van Erp HEG, GreenPJ (2004). Identification and Characterization of AtPARN, an essential poly (A) ribonuclease in *Arabidopsis*. *Gene* 328:95-102.

Johnson MA and Preuss D. (2003) On your mark, get set, GROW! LePRK2-LAT52 interactions regulate pollen tube growth. *Trends in Plant Sciences* 8: 97-99.

Kastenmayer JP, Johnson MA, and Green P.J. (2001) Analysis of XRN Orthologs by Complementation of Yeast Mutants and Localization of XRN-GFP Fusion Proteins. *Methods in Enzymol* 342: 269-82.

Pérez-Amador M, Lidder P, Johnson MA, Landgraf J, Wisman E, Green PJ. (2001) New Molecular Phenotypes in the dst Mutants of *Arabidopsis* Revealed by DNA Microarray Analysis. *Plant Cell* 12: 2703-2717.

Johnson MA, Perez-Amador M, Lidder P, Green PJ. (2000) Mutants of *Arabidopsis* defective in a sequence-specific mRNA degradation pathway. *PNAS* 97: 13991-13996.

(d) Synergistic Activities

Outreach. I have sought to broaden the participation of underrepresented groups in science by: serving on the Brown University MCB Graduate Program Admissions and Recruitment Committee (2005, 2007), by participating in efforts to establish research links between Brown University and North Carolina A&T State University (an historically black university), by working with the Brown University Leadership Alliance (a national program that provides summer research opportunities and career-long networking support for members of underrepresented groups), and by giving a research seminar and leading a workshop on career opportunities in Biology at Selman College, an historically black college that enrolls only women (2008). I strive to create a supportive environment in my lab that demonstrates that science is a viable career path for people of all backgrounds and I value the opportunity to help all students realize their scientific career goals. I am also working to bring our research to the broader educational community. Aubrey Frank, the graduate student in my lab, is an instructor for project ARISE, a Brown University, NIH-funded professional development program for Rhode Island high school biology teachers (2007-2008). I have collaborated with Josephine Pino, Director of the Biotechnology Program at the Community College of Rhode Island, and brought a student to my lab for an intersession research internship (2008). I created and led a lab exercise for a group seventh graders who spent the day in my department called, "Matching genotype to phenotype with PCR" (2008). I was a Member of Joint Steering Committee for Public Policy and Participated in Joint Steering Committee for Public Policy, Capitol Hill Day. June 9, 2004; during which, I met with congressional representatives and their staffs to discuss funding for biological research and the promise of stem cell research. I am a member of The American Society of Plant Biology. Ad hoc grant reviews: USDA National Research Initiative Competitive Grants Program (2003, 2005, 2006) National Science Foundation: Mechanisms of Plant Development (2003, 2005, 2006, 2008) National Science Foundation: International research fellowship program (2006). Manuscript Reviews: *Plant Molecular Biology (2003), Plant Physiology (2004, 2006-2008), Science (2003), The Plant Cell (2005-2008), The Plant Journal (2006-2008), Sexual Plant Reproduction (2006, 2007), Developmental Biology (2006), Molecular Plant (2008), PNAS (2008). Plant Science (2008), Development (2008), Nature (2008)*

(e) Collaborators & Other Affiliations

Collaborators and Co-Editors:
Aux, G. (Syngenta)
Chiba,Y. (U Delaware)
Frank, A. (Brown)
Green, P.J. (U Delaware)
Howard, C.J. (U Nevada-Reno)
Lidder, P. (NYU)
Levin J.Z. (Novartis)
Lord, E. (UC Riverside)
Palanivelu, R (Arizona)
Patton, D. (Syngenta)
Perez-Amador, M.A. (U Valencia, Spain)
Preuss, D. (HHMI, U Chicago)
Smith, E. (U Chicago)
Sullivan, M.L. (USDA)
Thompson, D.M. (U Arizona)
van Erp, H. (MSU)
Smith, E. (U Chicago)
Sullivan, M.L. (USDA)
Thompson, D.M. (U Arizona)
van Erp, H. (MSU)
Vogel, Jonathon T. (MSU)
Von Besser, K. (U Chicago)
Zhou, Q. (BASF)

Graduate and Postdoctoral Advisors:
Graduate: Green, P.J. (U. Delaware)
Postdoctoral: Preuss, D.P (U. Chicago)

Graduate and Postdoctoral Advisees
Graduate: Aubrey Frank (current)
Postdoctoral: Dr. Julian Wong (current)

BENJAMIN J. RAPHAEL
Assistant Professor
Department of Computer Science & Center for Computational Molecular Biology
Brown University, Providence, RI 02912
Phone: (401) 863-7643 FAX: (401) 863-7657
Email: braphael@brown.edu Web: cs.brown.edu/people/braphael

a. Professional Preparation

Massachusetts Institute of Technology	**S.B.** in Mathematics, **S.B. Minor** in Biology	1996
University of California, San Diego	**Ph.D.** in Mathematics	2002
University of California, San Diego	**Postdoctoral Fellowship** in Computer Science (Bioinformatics)	2002-2006

b. Appointments

2006-	**Assistant Professor**, Department of Computer Science & Center for Computational Molecular Biology, Brown University
2005-2006	**Burroughs Wellcome Postdoctoral Fellowship** in Computer Science (Bioinformatics), University of California, San Diego. Sponsor: Professor Pavel Pevzner.
2002-2004	**Alfred P. Sloan Postdoctoral Fellowship** in Computer Science (Bioinformatics), University of California, San Diego. Sponsor: Professor Pavel Pevzner.

c. Publications

Five publications most closely related to the proposed project:

Ritz A, Shakhnarovich G, Salomon AR, **Raphael BJ**. (2009) Identification of Phosphorylation Motif Mixtures in Phosphoproteomics Data. Bioinformatics. 25(1):14-21.

Sindi S and **Raphael BJ**. (2009) Identification and Frequency Estimation of Inversion Polymorphisms from Haplotype Data. *Proceedings of the 13th Annual International Conference on Research in Computational Molecular Biology (RECOMB)*. (In Press).

Kahn CL and **Raphael BJ.** Analysis of Segmental Duplications via Duplication Distance. (2008) *Bioinformatics*. 24(16):i133-8.

Bashir A, Volik S, Collins CC, Bafna V, and **Raphael BJ**. (2008) Evaluation of Paired-end Sequencing Strategies for Detection of Genome Rearrangements in Cancer. *PLOS Computational Biology*. 4(4):e1000051.

Chaisson M, **Raphael BJ,** and Pevzner P. (2006) Micro-inversions in Mammalian Evolution. *Proceedings of the Natational Academy of Sciences.* 103: 19824-19829.

Five other significant publications:

Raphael BJ, Volik S, Guiqing Huang, Waldman F, Costello J, Aerni S, Brown RP, Bashir A, Pienta K, Mills G, Bajsarowicz K, Paris P, Tao Q, Kuo W, Gray JW, Cheng J, Nefedov M, de Jong P, and Collins C. (2008). A sequence based survey of the complex structural organization of tumor genomes. *Genome Biology*. 9(3):R59.

S. Yooseph, G. Sutton, D.B. Rusch, A.L. Halpern, S.J. Williamson, K.Remington, J.A. Eisen, K..B. Heidelberg, G. Manning, W. Li, L. Jaroszewski, P. Cieplak, C.S. Miller, H. Li, S. T. Mashiyama, M. P. Joachimiak, C. van Belle, J. Chandonia, D. A. Soergel, Y. Zhai, K. Natarajan, S. Lee, **BJ Raphael**, V. Bafna, R. Friedman, S. E. Brenner, A. Godzik, D. Eisenberg, J.E. Dixon, S. S. Taylor, R.L. Strausberg, M. Frazier, J.C. Venter. (2007) The Sorcerer II Global Ocean Sampling Expedition: Expanding the Universe of Protein Families. *PLOS Biology.* 5(3):e16.

Agler J, Harland J, **Raphael BJ.** (2008) Classical Function Theory, Operator Dilation Theory, and Machine Computation on Multiply-Connected Domains. *Memoirs of the American Mathematical Society*. Vol. 191, No. 892.

Raphael BJ, Zhi D, Tang H, and Pevzner P. (2004) A Novel Method for Multiple Alignment of Sequences with Repeated and Shuffled Domains. *Genome Research,* 14: 2336-2346.

Raphael BJ, Volik S, Collins C, and Pevzner P. (2003) Reconstructing Tumor Genome Architectures. *Bioinformatics*, Suppl 2: ii162-171. (Special ECCB 2003 Issue).

d. Synergistic Activities

2005-2006	Mentoring of female computer science undergraduates Sarah Aerni and Jean Yeh and underrepresented minority bioinformatics student Erik Corona.
2006-present	Advising female computer science Ph.D. students Anna Ritz and Crystal Kahn.
2007-present	Steering Committee: RECOMB Satellite Workshop on Computational Cancer Biology.
2007-present	Computational Molecular Biology Curriculum Committee, Brown University.
2008-present	Scientific Advisory Committee, NSF-EPSCoR Rhode Island Genomics and Sequencing Center

e. Collaborators & Other Affiliations

(i) Collaborators

Vineet Bafna, University of California, San Diego
Colin Collins, University of California, San Francisco

(ii) Ph.D. Advisor

Jim Agler, University of California, San Diego

(iii) Postdoctoral Sponsor

Pavel Pevzner, University of California, San Diego

Peter Damian RICHARDSON

(i) Professional Preparation
Undergraduate Institution: City & Guilds College of the Imperial College of Science, Technology and Medicine, of the University of London

Major: Mechanical Engineering

Degrees and Date: B.Sc.(Eng.) with honours, A.C.G.I. 1955

Graduate Institution: Imperial College of Science, Technology and Medicine, of the University of London

Major: Mechanical Engineering

Degrees and Date: Ph.D., D.I.C. 1958

Postdoctoral: In my country of origin one can take Higher Doctorates based on examination of published works and subject to University Regulations, candidacy being restricted by earlier degrees; I have successfully completed two of these at the University of London:

D.Sc.(Eng.) in Mechanical Engineering 1974
D.Sc. in Applied Physiology 1983

(ii) Appointments:
1984 - present Professor of Engineering and Physiology, Brown University, Providence RI
1968 - 1984 Professor of Engineering, Brown University
1965 - 1968 Associate Professor of Engineering, Brown University
1960 - 1965 Assistant Professor of Engineering, Brown University
1959 - 1960 Research Associate, Brown University, Providence RI
1958 - 1959 Visiting Lecturer, Brown University, Providence RI
1955 - 1958 Demonstrator, Department of Mechanical Engineering, City & Guilds College of Imperial College of Science, Technology and Medicine, London, UK

Honors: Fellow of the Royal Society, 1986; Laureate in Medicine, Ernst Jung Foundation, 1987; Founding Fellow, American Inst Medical and Biological Engineering, 1991; Fellow, City and Guilds of London Institute, 1993

(iii) Publications
(i) Closely related to proposed project - undergraduate student authors marked with *:

Sobel JS, Forsberg A, Laidlaw D, Zelenik R, Keefe D, Richardson PD, Karniadakis GE, Pivkin I. Particle flurries: A case study of synoptic 3D pulsatile flow visualization. (Feature Article) IEEE computer Graphics and Applications 24(2): 76-85, 2004

Pivkin, IV, Richardson, PD, Laidlaw, DH, Karniadakis, GE. Combined effects of pulsatile flow and dynamic curvature on wall shear stress in a coronary artery bifurcation model. J Biomechanics 38: 1283-1290, 2005.

Richardson, PD. Mechanical properties of atherosclerotic tissues. Proceedings of International Union of Theoretical and Applied Mechanics (IUTAM) Symposium; publ. in: Mechanics of Biological Tissue, Holzapfel GA, Ogden RW, eds. Springer-Verlag, pp. 207-223, 2006.

Guo D, Richardson P. Detection of cardiac cycle from intracoronary ultrasound. Ultrasound in Medicine and Biology 32: 345-356, March 2006.

Richardson, PD, Pivkin IV, Karniadakis GE, Laidlaw DH. Blood flow at arterial branches: complexities to resolve for the angioplasty suite. Alexandrov VN, van Albada GD, Sloot PMA, Dongarra J (eds.) Computational Science - ICCS 2006, Part III, Lecture Notes in Computer Science 3993, 538-545, Springer-Verlag Berlin Heidelberg 2006.

(iii) Other publications (from list >200)
(ii) Others of some relevance:

Richardson PD, Davies MJ, Born GVR. Influence of plaque configuration and stress distribution on fissuring of of coronary atherosclerotic plaques. Lancet ii: 941-944, 1989

Lendon C, Davies MJ, Born GVR, Richardson PD. Atherosclerotic plaque caps are weakened when macrophage density is increased. Atherosclerosis 87: 87-90, 1991

Richardson PD. Biomechanics of plaque rupture: progress, problems, and new frontiers. Ann. Biomed Engineering 30: 524-536, 2002

Pivkin IV, Richardson PD, Karniadakis G. Blood flow velocity effects and role of activation delay time on growth and form of platelet thrombi. Proc. Nat. Acad. Sci. U.S. 103(46): 17164-17169, 2006

Richardson PD. Malaria in the microcirculation: Mechanics from histology. Proc 34th Ann Northeast Bioengineering Conf, pp.219-220, 2008

(iv) Synergistic and Related Activities
(a) I have sponsored undergraduate research projects since my time as an Assistant Professor - not all of it rises to the point of publication.
(b) I have given emphasis to mathematical methods and comparison with experiments, widely over these decades.
(c) Beginning about 1969, when a colleague and I established an artificial organs research program and concurrent course, I have included biological and medical applications, and as I moved further into study of disease processes this has involved undergraduates in more research.
(d) In upper-level undergraduate courses, such as in Biomechanics, I have all students carry out projects for a significant fraction of a semester and this helps identify students to be recruited into further undergraduate research activities.

(v) Collaborators

(a) Forsberg, A, Keefe, DF, Karniadakis, GE, Laidlaw, DH, Maxey, M, Pivkin, IV, Sobel, JA, Zelrnik, R, all at Brown University; Born GVR, Harvey Inst., London
(b) Prof Sir Owen Saunders FRS (deceased) PhD thesis advisor, Profs J Kestin, H Sogin (both deceased) post-doc sponsors.
(c) Guo, D, PhD, Oracle Corp, NH

Arthur Salomon

Assistant Professor
Molecular Biology, Cell Biology, Biochemistry, and Chemistry
Brown University
Providence, RI 02912

Phone: (401) 648-6907
Fax:
Email: Arthur_Salomon@brown.edu

Education

1995 B.S. in Chemistry, Case Western Reserve University, Cleveland, OH
2000 Ph.D. in Chemistry, Stanford University, Stanford, CA,
2004 Postdoc, Proteomics, Genomics Institute of the Novartis Research Foundation, San Diego, CA

Experience

2006-Marine Biological Laboratory Invited Lecture
Invited Talk: “Phosphoproteomic analysis of signaling pathways”, Woods Hole, MA
2006-NIH Study Section ZRG1 BST-D(51) Continued Development and Maintenance of Software, September 2006.
2005-Institute for Diabetes, Obesity, & Metabolism seminar series-U. of Pennsylvania
Invited Talk: “Unraveling the molecular circuitry of cells using phosphoproteomics”, Philadelphia, PA
2005-3rd Lymphocyte Signal Transduction Workshop
Invited Talk: “Unraveling molecular circuitry in immunological signaling cascades using phosphoproteomics”, Crete, Greece
2005-NIH Study Section ZRG1 BST-D(55) National Technology Centers for Networks and Pathways
2005-COBRE CCRD Third Annual Research Symposium
Invited Talk: “Unraveling the molecular circuitry of cells and disease using phosphoproteomics”, Rhode Island Convention Center, Providence, RI
2005-Allergy/Immunology Grand Rounds, Brown Medical School
Invited Talk: “Phosphoproteomic analysis of mast cell signaling”, Rhode Island Hospital, Providence, RI
2004-Assistant Professor, Brown University, Providence, RI
2004-52nd ASMS Conference on Mass Spectrometry and Allied Topics
Talk: “Unraveling the Molecular Circuitry in Immunological Signaling Cascades Using Phosphoproteomics”. Nashville, TN
2004-227th ACS National Meeting
Invited Talk: “High-throughput phosphoproteomics: Unraveling the molecular circuitry of the human cell”, Anaheim, CA
2003-present Associate Professor, Computer Science Department, Brown University
2000-2003 Stephen Robert Assistant Professor, Computer Science Department, Brown University
2000-Post doctoral fellow-Genomics Institute of the Novartis Research Foundation, San Diego, CA
1995-Graduate student-Chemistry Department at Stanford University

Selected Publications

• L. Cao, K. Yu, V. Nguyen, Y. Kawakami, T. Kawakami, A. Salomon (2007). "Quantitative Phosphoproteomic Analysis of Mast Cell Signaling." J. Immunology, 179(9):5864-5876.

• H. Yu, I. Lee, A. Salomon, K. Yu, M. Huttemann (2008). “Mammalian liver cytochrome c is tyrosine-48 phosphorylated in vivo, inhibiting mitochondrial respiration.” BBA-Bioenergetics, 1777(7-8): 1066-71.

• A. Ritz, G. Shakhnarovich, A. Salomon, B. Raphael (2008). “Discovery of phosphorylation motif mixtures in phosphoproteomics data.” Bioinformatics, 25(1):14-21.

• I. Lee, A. Salomon, K. Yu, Samavati, L., Pecina, P., Pecinova, A., Hüttemanna, M. (2009). "Isolation of regulatory-competent, phosphorylated cytochrome c oxidase." Methods Enzymol, 457, in press

• V. Nguyen, L. Cao, J. T. Lin, N. Hung, A. Ritz, K. Yu, R. Jianu, B. J. Raphael, D. H. Laidlaw, L. Brossay, A. Salomon (2009). “A new approach for quantitative phosphoproteomic dissection of signaling pathways applied to T cell receptor activation.” Molec. Cell. Proteomics, in press.

Other Publications

• E. Peters, A. Brock, Q. Phung, J. Fitchett, D. Horn, C. Ericson, S. Ficarro, A. Salomon (2002). “Automated Liquid Chromatography MALDI FT-ICR MS Platform for Proteomics: Rationale for an Off-Line Approach and Optimized Implementation” Am. Pharma. Rev., 5(3): 72-81.

• Brock, D. Horn, C. Shaw, E. Peters, C. Ericson, Q. Phung, S. Ficarro, A. Salomon (2002). “FT-ICR MS Platform for Proteomics: Automated High Performance Mass Spectrometry and Data Analysis” Am. Pharma. Rev., 5(4): 94-99.

• L. Cao, K. Yu, A. Salomon (2006). “Phosphoproteomic Analysis of Lymphocyte Signalling.” In Advances in Experimental Medicine and Biology, Vol. 584, CD Tsoukas, ed. Springer, New York, NY. Pgs. 277-88.

• I. Lee, A. Salomon, K. Yu, J. Doan, L. Grossman, M. Huttemann (2006). “New Prospects for an Old Enzyme: Mammalian Cytochrome c Is Tyrosine Phosphoryalted In Vivo.” Biochemistry. 45(30): 9121-9128.

• T. Nuhse, A. Salomon (2007). “Isolation of Phosphopeptides by Immobilized Metal Affinity Chromatography.” In Cur. Prot. Mol. Biol., (Ausubel et al., eds.) 18.13.1-18.13.23. John Wiley & Sons, Hoboken, N.J.

Synergistic Activities

Collaborators and Other Affiliations

Advisees: Vinh Nguyen, Kebing Yu, Lulu Cao, Yiyuan Ding

E. Biographical Sketches: Sharon Miriam Swartz

A. *PROFESSIONAL PREPARATION*

1977-1981	B.A.	Oberlin College. Biology and Sociology/Anthropology, High Honors
1982-1985	M.S.	The University of Chicago. Evolutionary Biology
1985-1988	Ph.D.	The University of Chicago. Evolutionary Biology

B. *APPOINTMENTS*

1996-present	Associate Professor, Brown University, Department of Ecology and Evolutionary Biology Adjunct Associate Professor, Division of Engineering
February – July, 1996	Parental Leave
1990-1996	Assistant Professor, Brown University, Department of Ecology and Evolutionary Biology Adjunct Assistant Professor, Division of Engineering
April – August, 1993	Parental Leave
1987-1990	Assistant Professor, Northwestern University Medical School, Department of Cell Biology & Anatomy; & Northwestern University College of Arts & Sciences, Department of Anthropology

C. *PUBLICATIONS*: Five most closely related to proposed project (undergraduate co-authors in bold)

Riskin, D. K., D. J. Willis, J. Iriarte-Diaz; T. L. Hedrick; M. Kostandov, J. Chen; D. H. Laidlaw, K. S. Breuer, and S. M. Swartz. 2008. Quantifying the complexity of bat wing kinematics. Journal of Theoretical Biology 254:604-615.

Swartz, S. M. and K. M. Middleton. 2008. Biomechanics of the Bat Limb Skeleton: Scaling, Material Properties and Mechanics. Cells, Tissues, and Organs 187:59-84.

Willis, D. J., M. Kostandov, D. K. Riskin, J. Peraire, D. H. Laidlaw, S. M. Swartz, K. S. Breuer. 2007. Modeling the Flight of a Bat: First Place, Informational Graphics, International Visualization Competition. *Science* 317:1860.

Swartz, S. M., K. L. Bishop **and M. F. Ismael-Aguirre. 2006**. Dynamic complexity of wing form in bats: implications for flight performance. Pp. 110-130 in Functional and Evolutionary Ecology of Bats (Z. Akbar, G. McCracken, & T. H. Kunz, eds). Oxford University Press.

Swartz. S. M., M. B. Bennett, and D. R. Carrier. 1992. Wing bone stresses in free flying bats and the evolution of skeletal design for flight. Nature 359:726-729.

(II). Five other:

Swartz, S. M. 1997. Allometric patterning in the limb skeleton of bats: Implications for the mechanics and energetics of powered flight. Journal of Morphology 234:277-294.

Swartz, S. M., **M. D. Groves**, **H. D. Kim** and W. R. Walsh. 1996. Mechanical properties of bat wing membrane skin: aerodynamic and mechanical functions. Journal of Zoology, London 239:357-378.

Swartz, S. M., **A. Parker**, and **C. Huo**. 1997. Theoretical and empirical scaling patterns and topological homology in bone trabeculae. Journal of Experimental Biology 201:573-590.

Papadimitriou, H. M., S. M. Swartz, and T. H. Kunz. 1996. Ontogenetic and anatomic variation in mineralization of the wing skeleton of the Mexican free-tailed bat, *Tadarida brasiliensis*. Journal of Zoology, London, 240:411-426.

Swartz, S. M., A. A. Biewener, and J. E. A. Bertram. 1989. Telemetered *in vivo* strain analysis of locomotor mechanics of brachiating gibbons. Nature 342:270-272.

D. *SYNERGISTIC ACTIVITIES:*

1. *Selection and Steering Committee, Brown University Undergraduate Research and Teaching Assistantships Program* — the UTRA program supports student-faculty collaboration in both scholarly research and course development. Since 1994, I have A) helped to select over 2500 projects; B) sponsored over 60 undergraduate research projects in my lab; C) developed Team UTRA Grants, designed to extend the opportunity for hands-on research experiences to thoughtfully constructed larger teams (3-10 members) of students, enriching and facilitating the way students become immersed in scholarly research and offering opportunities to many more students than is possible in solely one student/one teacher projects.

2. *Brown representative for Project Kaleidoscope (PKAL) Faculty for the 21st (F21) Century* — PKAL is a national organization devoted to building and connecting leaders shaping the future of undergraduate studies of science, mathematics, engineering and technology at the university level. F21 representatives participate in an alliance of scientists and institutions studying and working to transform the learning environment for undergraduate students in SME&T.

3. *Affinity Group Leader and Steering Committee Member, Brown Women in Science and Engineering (WiSE) Program* —WiSE provides diverse support and mentorship opportunities to undergraduates with interests in SME&T. As an Affinity Group Leader, I mentor women with career interests in biology and provide them ongoing academic advice, career counseling, and support, with special attention to the needs and issues of women in fields in which they have been traditionally underrepresented.

4. K-12 *Biology Outreach Analysis* — member of Brown Education Department team evaluated success of NSF MSP Program to improve K-12 SME&T education, analyzing specific changes in challenging biology curricula and incorporation of primary research into K-12 programs.

5. *Context-Rich Interactive Science Teaching and Learning System (CRISTALS) Faculty* — projects to develop more effective techniques to teach fundamental, core scientific concepts that recur throughout university level science education. Pilot project supported by NSF-CCLI program: http://www.geo.brown.edu/geocourses/QE/CRISTAL_SE/

E. *COLLABORATORS AND OTHER AFFILIATIONS:*

(i): Collaborators: Dr Janet Blume, Brown University; Dr. Patricia Freeman, University of Nebraska; Dr. Thomas Kunz, Boston University; Drs. David Carrier and John Skedros, University of Utah.

(ii): Graduate Advisors: Dr. Andrew A. Biewener, Harvard University; Dr. Russell H. Tuttle, The University of Chicago; No postdoctoral advisor

(iii): Thesis Advisor and Postgraduate-Scholar Sponsor: past thesis advisees: Dr. Jennifer Chickering; Dr. Kathleen Earls; present: Kristin Bishop (NSF GRF), José Iriarte-Diaz, Joseph Bahlman (NSF GRF)

(iv): Postdoctoral advisees: Dr. Daniel Riskin, Dr. Tatjana Hubel, Dr. Xiaodong Tian, Dr. Kevin Middleton, Dr. Gregory Erickson, Dr. Katherine Rafferty; Dr. Elizabeth Stockwell, Dr. Philip Watts

KRISTI ANNA WHARTON
Department of Molecular Biology, Cellular Biology and Biochemistry, Brown University
Providence, RI 02912. Phone: (401) 863-1951; FAX (401) 863-1348;
Kristi_Wharton@brown.edu

(i) Professional Preparation

Cornell University	Biology	A.B. 1978
Yale University	Biology	Ph.D. 1986
Yale University	Developmental Genetics	7/87 – 8/87
University of Crete, Greece	Developmental Genetics	9/87 – 12/87
Harvard University	Developmental Genetics	1988 - 1991

(ii) Appointments

2001-present	Associate Professor, MCB Dept., Brown University
2003	Professor, Department of Cell Biology, Biozentrum, University of Basel, Switzerland (sabbatical leave)
2000 - 2001	Manning Assistant Professor, Brown University
1995 - 2001	Assistant Professor, MCB Dept., Brown University
1991 - 1995	Assistant Professor (Research), Brown University

Awards

2005	Elizabeth Leduc Award for Excellence in Teaching in the Life Sciences
2003	Manning Assistant Professor, Brown University
1994-99	Established Investigatorship, American Heart Association
1988-91	NIH NRSA postdoctoral fellowship, Harvard University
1987	EMBO Short Term Fellowship, IMBB, Crete, Greece
1986-87	Sessil B. Anonymous Fellowship, Yale University
1982-86	NIH NRSA training grant in Genetics, Yale University

(iii) Publications

(i) closely related to proposed project

1. Bangi, E. and Wharton, K. A. (2006). Dual function of the Drosophila ALK1/ALK2 orthologue, Saxophone, influences the BMP activity gradient critical for wing patterning. **Development** 133, 3295-3303.

2. Bangi, E. and Wharton, K.A. (2006) Dpp and Gbb exhibit different effective ranges in the establishment of the BMP activity gradient critical for Drosophila wing patterning. **Developmental Biology** 295, 178-193.

3. Ray, R. and Wharton, K.A. (2001) Context-dependent relationships between the BMPs *gbb* and *dpp* during development of the *Drosophila* wing imaginal disc. **Development** 128, 3913-3925.

4. Wharton, K. A., Cook, J., Torres-Schumann, S., de Castro, K., Borod, E. and Phillips, D.A. (1999) Genetic analysis of the BMP-related gene, *gbb*, identifies multiple requirements during *Drosophila* development. **Genetics** 152, 629-640.

5. Khalsa, O., Yoon, J-W., Torres-Schumann, S. and Wharton, K.A. (1998) TGF- /BMP superfamily members, Gbb-60A and Dpp, cooperate to provide pattern information and establish cell identity in the *Drosophila* wing. **Development** 125: 2723-2734.

(ii) other significant publications

1. Sinenko, S.A., Kim, E.K., Wynn, R., Manfruelli, P., Ando, I., **Wharton, K.A**., Perrimon, N. and Mathey-Prevot, B. (2004). *Yantar* is a novel and evolutionary conserved gene involved in *Drosophila* hemocyte differentiation. **Developmental Biology** 273: 48-62.
2. Haerry, T. E., Khalsa, O., O'Connor, M.B. and Wharton, K.A. (1998) Synergistic signaling by two BMP ligands through the SAX and TKV receptors controls wing growth and patterning in *Drosophila*. **Development** 125, 3977-3987.
3. Wharton, K.A., Ray, R.P., Findley, S.D., Duncan, H.E. and Gelbart, W.M. (1996) Molecular lesions associated with alleles of *decapentaplegic* identify residues necessary for TGF-ß/ BMP cell signaling in *Drosophila melanogaster*. **Genetics** 142, 493-505.
4. Wharton, K.A., Ray, R. and Gelbart, W.M. (1993) An activity gradient of *decapentaplegic* is required for dorsal-ventral patterning in the *Drosophila* embryo. **Development** 117, 807-822.
5. Wharton, K.A., Johansen, K.M., Xu, T. and Artavanis-Tsakonas, S. (1985) Nucleotide sequence from the neurogenic locus *Notch* implies a gene product which shares homology with proteins containing EGF-like repeats. **Cell** 43, 567-581.

(iv) Synergistic Activities

- Development of datasets and methodology to make use of VR in teaching embryology
- Review grant proposals and participate in study section for the Academy of Finland, American Cancer Society, NSF (Developmental mechanisms, International programs), NIH
- Review manuscripts for numerous journals
- Travel to give seminars, establish collaborations, attend scientific meetings

(v) Collaborators & Other Affliations

Collaborators in the last 48 months:
E. Bangi (Novartis, Cambridge,MA); L. Soares (Brown), S. Ballard (Brown), Jurgen Schulze (UCSD), Andy Forsberg (Brown), Jamie Weaver (Brown), Jennifer Shagensky (Brown), Michael Shim (Brown), Toni-Marie Ferruccio (Brown), Frederick Kaplan (Univ. Penn), Eileen Shore (Univ. Penn)
Graduate Advisor:
Spyros Artavanis-Tsakonas, Department of Cell Biology, Harvard Medical School
Postdoctoral Advisors:
Spyros Artavanis-Tsakonas, Department of Cell Biology, Harvard Medical School;
Fotis Kafatos, Chair Immunogenomics, Department of Cell & Molecular Biology, Imperial College, London; Christos Louis, IMBB, University of Crete, Greece; William Gelbart, Department of Cell and Developmental Biology, Harvard University
Thesis Advisor and PostGraduate-Scholar Sponsor:
Postdoctoral Advisees: Rochele Yamamoto (Brown), Robert Ray (Univ. of Sussex, UK)
Graduate Advisees: Ongkar Khalsa (Julia Lamenzo) (Broad Institute, M.I.T.), Jung-won Yoon (Stanford University), Caroline Savery (Brown University), Erdem Bangi (Novartis, Cambridge, MA), Lorena Soares (University of Pennsylvania), Shannon Ballard (Brown University), Maryanna Aldrich (Brown University)

Facilities and other Resources

Brown's Center for Computation and Visualization (CCV) maintains an 800 sq ft. raised-floor machine room and adjacent 900 sq ft. Virtual Reality laboratory. The VR laboratory contains the 8-year old Tan Cave, graphics workstations used for applications development, and a 6-foot square 3x3 tiled stereo wall display recently built as an experimental prototype for planning and design of the new Cave. Both the Cave and the wall display have wired magnetic and inertial/ultrasonic tracking systems, and use field-sequential stereo projection.

The machine room houses roughly 150 Linux computing nodes in several clusters, all running the ROCKS cluster Linux distribution (www.rocksclusters.org) and dedicated to research computing applications. These clusters variously use Infiniband, Myrinet and Gigabit Ethernet as messaging interconnects, and all are connected via trunked Gigabit Ethernet to a 40 terabyte Lustre (www.clusterfs.com) parallel fileservice network. In addition, there are three Linux clusters that can be switched to drive either the wall or the Cave display: 1) the 4-year old 48-node Linux cluster with 1.7 GHz Xeon processors, RDRAM memory, low-end AGP graphics cards and Myrinet, 2) a 5-node Linux cluster with Myrinet, and 3) a 5-node Linux cluster with Gigabit Ethernet. "1)" and "2)" are connected to the Lustre filesystem.

A Tivoli TSM server is used for off-line data cache, archival and backups, with 4 terabytes of attached staging disk and a 600 terabyte (uncompressed) Qualstar LTO-3 tape library.

The CCV networks are attached to the Brown backbone network via Gigabit Ethernet and a scalable system of Linux firewall nodes. The Brown network is in turn connected to the Internet via an OC-3 link to OSHEAN, the Rhode Island Ocean State Higher Education and Administration Network (www.oshean.org) , which maintains Internet-2 and commercial Internet connectivity.

The CCV machine room and graphics laboratory are secured by Brown ID card-swipe door locking systems.

The new Cave will replace the 8-year old Tan Cave, and the visualization cluster will be added to the machine room. The old visualization cluster will be maintained for 1-2 years as a general parallel computing resource.

The machine room air-conditioning is provided by a chilled-water system with a dedicated 40-ton chiller and fail-over supply from a local campus chilled water piping loop. An additional 15-ton mechanical system provides backup cooling.

Samuel G. Fulcomer

Associate Director, Center for Computation and Visualization (CCV)
Brown University
Providence, RI 02912

Professional Preparation

1976 – 1978 Undergraduate Student, Brown University

Appointments

2006- Present	Associate Director, Center for Computation and Visualization, Brown University
1998- 2006	Director, Technology Center for Advanced Scientific Computing and Visualization, Brown University
1997 – 1998	Associate Director, Center for Advanced Computing Research, California Institute of Technology
1987–1997	Associate Director, Center for Fluid Mechanics, Brown University
1987-1997	Systems and Software Engineering Consultant
1986-1987	Software Engineer, Image Management Systems, Providence, RI
1984-1986	Technical Support Specialist, Institute for Research in Information and Scholarship, Brown University

Publications

Prabhat, Samuel G. Fulcomer, “Experiences in driving a Cave with IBM SGE-3 prototypes” ACM VRST 2005.
J. W. Head, A. van Dam, S. Fulcomer, A. Forsberg, Prabhat, G. Rosser, S. Milkovich, “ADVISER: Immersive Scientific Visualization applied to mars research and exploration” PE&RS special issue on Mars Mapping, 2005.

Computer Animated Films*:*
“Eigenfunctions in Homogeneous Turbulence”, with Huseyin Kocak, Ken Ball, Frederic Bisshopp, Martin Maxey, and Lawrence Sirovich (October 1987); version II, (January 1988)

Synergistic Activities

Numerical software parallelization and optimization
Distributed parallel graphics rendering
Relational and object database systems for scientific datasets
System software engineering and integration
Design, implementation and optimization of parallel systems
Management of large-scale parallel computing facilities
Management of scientific computing user services groups
Scientific visualization
Virtual Reality display design and implementation
Benchmarking and architecture evaluation
UNIX systems management
Network and peripheral UNIX device driver development
UNIX NFS server development
Kernel Streams modules development
File system development
High-performance network design, implementation and management

Collaborators & Other Affiliations
James Head III, Professor, Geological Sciences, Brown University; Andries van Dam, Professor of Computer Science, Brown University

Graduate and Postdoctoral Advisors
None

Thesis Advisor
None

BROWN

Office of Sponsored Projects

January 21, 2009

Dr. Randy Phelps
Office of Integrative Activities
Major Research Instrumentation Program
National Science Foundation, Room 1270
4201 Wilson Boulevard
Arlington, VA 22230

RE: "MRI: Development of a Next-generation Interactive Virtual-Reality Display Environment for Science"

PI: David Laidlaw, Brown University

Dear Dr. Phelps:

As required by NSF 09-502, this letter confirms the classification of Brown University as a Ph. D. granting organization.

Please contact me at your convenience with any concerns. Thank you.

Sincerely,

Eva J. Faling
Contract Administrator
(401) 863-1291
Eva_Faling@Brown.edu

John N. Huffman

Box 1824, Brown University
Providence, RI 02912
John_Huffman@brown.edu

Graphics Programmer, System Administrator, Computer Technologist

11 years of professional graphics programming and system administration experience, with an emphasis on high-end graphics systems.

Professional Experience

Sept. 2007 – Present **Graphic Systems Analyst, Center for Computation and Visualization (CCV), Brown University** Support and collaborate with Brown University researchers, providing high end visualization hardware and software solutions. Maintain existing visualization facilities, and pursue grants and projects that broaden and enhance visualization at Brown.

Jan. 2006 –August 2007 **Lead Analyst/Programmer for IU Teragrid Visualization, Advanced Visualization Lab (AVL), University Information Technology Services (UITS), Indiana University (IU)** Create and manage visualization projects and resources associated with IU's Teragrid strategy. Primary focus on creation and administration of a Teragrid enabled distributed rendering system utilizing unused desktop cycles (2800 Windows systems) and advanced Teragrid visualization users support.

Oct. 2000 – Dec. 2005 **Senior Technology Coordinator, Advanced Visualization Lab (AVL), University Information Technology Services (UITS), Indiana University (IU)** Duties include manage and maintain CAVE virtual reality facilities, across multiple Indiana University campuses. Also includes setup and installation of new facilities and equipment to solve visualization and tele-collaboration problems. As part of my job I have written several multi-million dollar RFPs(Request for Purchase) for Indiana University equipment grants, and then helped manage the purchase, installation and integration of this equipment

Sept. 1997 – Oct 2000 **CAVE Facility Support Technician, AVL, UITS** Administration of AVL machines, including SGI, Linux, Solaris, and MS Windows systems. Maintain and support of AVL CAVE facility and software/hardware support. Software development for scientific visualization, virtual reality, and systems support. Maintain user account and provide expert support for IU faculty, staff, and students. This included the system administration for a 16 CPU SGI Origin 2000 supercomputer, with over 130 users.

Mar. 1996 – Aug. 1997 **Computer Technologist, Center for Innovative Computer Applications (CICA)**. Administration of the CICA Unix machines, including SGIs, Suns and Linux PCs. Collaborative computer visualization projects involving other university organizations. Coordinated vendor relations for small and large projects, including purchases of CICA computer hardware and a teraflop supercomputer. Acting administrator for the IU CAVE.

Skills

Programming Languages:
- Working knowledge of C, C++, Java, Perl and HTML.
- Experience with FORTRAN77, FORTRAN90, Pascal, BASIC, TCL/TK, and various Unix shells.

Programming APIs:
- Working knowledge of OpenGL, Glut, CAVE API, GTK, VTK, Motif
- Experience with IrisPerformer, OpenInventor, IrisGL, VRML1, VRML2, OSG

Application Programs:
- Graphics Programs: GIMP, XV, Adobe PhotoShop
- 3D Modeling: AC3D, Wavefront, Alias, Maya, 3DS Max, Blender
- Extensive use of Scientific Visualization programs, such as Rasmol. Qmol, Paraview, VMD, OpenDX

Networking and Administration:

- File systems support, account administration, shell scripting, security auditing, firewalls
- Network installation and troubleshooting, NIS, NFS, SAMBA, sendmail/Postfix, mailing lists
- Hardware integration, device drivers, HID support

Major Projects

Invented and developed a novel 3D portable immersive visualization system, known as the John-e-Box. The system was licensed and is now being marketed commercially by CAE-net, Inc. (*http://www.cae-net.com*). Commercial systems were later distributed to nine different locations, across four campuses, as well as the Indiana Museum of Art (*http://www.ima-art.org*).

Set up multiple Access Grid (AG) sites, including four full multi-projection AG systems across two IU Campuses. As part of the project I developed software and web pages to allow private AG rooms for AG 1.2, as well as desktop versions for tele-collaboration.

Awards/Publications

Sandvoss, Harwood, Korkmaz, Bollinger, Huffman and Huffman. Common Molecules: Bringing Research and Teaching Together through an Online Collection. *Journal of Science Education and Technology*, Vol. 12, No. 3, September 2003

Super Computing 2003 High Performance Challenge Award: Global Analysis of Anthropod Evolution

Super Computing 1998 High Performance Challenge Award: Best Industrial Collaboration: Industrial Mold Filling Simulation Using an Internationally Distributed Software Component Architecture

Education

Purdue University, West Lafayette IN, 47906
Bachelor of Science, Dec. 1995 – Major: Computer Science, Minor: Psychology

Conferences/Presentations

- *Supercomputing 2006:* Presentation at Indiana Booth: Distributed Rendering Using Condor
- *Teragrid 2006:* Presentation: Lustre WAN Demonstration*. D. Balog, J. Huffman, G. Pike, S. Simms*
- *Supercomputing 2004:* Exhibitor and technical staff at Research in Indiana booth
- *Supercomputing 2003:* Exhibitor and technical staff at Research in Indiana booth, demonstration of John-e-Box Technology
- *Supercomputing 2002:* Exhibitor and technical staff at Research in Indiana booth, application demonstration
- *Supercomputing 2001:* Exhibitor and technical staff at Research@Indiana booth
- *Supercomputing 2000:* Exhibitor and technical staff at Research@Indiana booth
- *Supercomputing 98*: iGrid Research Booth: Exhibitor and technical staff, application demonstration.
- *Supercomputing 97*: Indiana University Research Booth: Exhibitor and technical staff, applications demonstration
- *Alliance 97*: Immersive Chemical Visualization: Application presentation

BROWN

CLYDE L. BRIANT
Vice President for Research

January 22, 2009

Dr. Randy Phelps
Office of Integrative Activities
Major Research Instrumentation Program
National Science Foundation, Room 1270
4201 Wilson Boulevard
Arlington, VA 22230

Re: "MRI: Development of a Next-generation Interactive Virtual-Reality Display Environment for Science"

Dear Dr. Phelps:

This letter regards the application by Brown University investigator Professor David Laidlaw from the Department of Computer Science. Prof. Laidlaw is requesting support from the NSF for his proposal to the **Major Research Instrumentation Program**, to build an immersive display environment for scientific data analysis.

The University is committed to supporting this worthwhile proposal, and will provide a total match of $764,320 over the four years of the grant. I encourage you to give this proposal your highest consideration.

Sincerely yours,

Clyde Briant
Vice President for Research
Otis E. Randall University Professor

Brown University Box 1937 Providence, RI 02912 TEL: 401 863-7408 FAX: 401 863-9994 Clyde_Briant@Brown.edu