02 INFORMATION ABOUT PRINCIPAL INVESTIGATORS/PROJECT DIRECTORS(PI/PD) and co-PRINCIPAL INVESTIGATORS/co-PROJECT DIRECTORS

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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:
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Black or African American. A person having origins in any of the black racial groups of Africa.
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White. A person having origins in any of the original peoples of Europe, the Middle East, or North Africa.

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PI/PD Name: David Badre

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: Steven A Sloman

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

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PI/PD Name: Mark J Schnitzer

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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- ☐ None

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List of Suggested Reviewers or Reviewers Not To Include (optional)

SUGGESTED REVIEWERS:
Not Listed

REVIEWERS NOT TO INCLUDE:
Not Listed

List of Suggested Reviewers or Reviewers Not To Include (optional)

SUGGESTED REVIEWERS:
Not Listed

REVIEWERS NOT TO INCLUDE:
Not Listed

COLLABORATORS/INDIVIDUALS WITH CONFLICTS OF INTEREST

Acevedo D, KAUST
Ahrens ET, CMU
Akelman E, Brown University
Albert Martin, Boston VA/BU
Barbey Aron, NIH
Barr AH, Caltech
Barredo Jennifer, Brown
Benjamin Flusberg, Pacific Biosciences
Bennett J, UCHSC
Bennur, Sharath, University of Pennsylvania
Bes Benedicte, University of Toulouse II, France
Bonnefon Jean-Francois, University of Toulouse II, France
Brennan-Krohn T, Providence VA Hospital and Butler Hospital
Breuer KS, Brown University
Brossay L, Brown University
Brown M, UCHSC
Buckner Randy, Harvard University
Butkiewicz Thomas, UNC Charlotte/University of New Hampshire (Co-author)
Butner Scott, Pacific Northwest National Laboratory (Internship mentor)
Callan-Jones AC
Cao L, Brown University
Carter Cameron, UC Davis
Chang Remco, UNC Charlotte/Tufts University (Co-author)
Chen J, Souther Mississippi University
Clark RC, Flinders University (Australia)
Cohen R, Brown University
Conley J, Brigham and Women's Hospital
Connolly, Patrick, University of Pennsylvania
Coop K, Miriam Hospital
Corboy J, UCHSC
Correia S, Providence VA Hospital and Butler Hospital
Crisco JJ, Brown University
Curran Kent, UNC Charlotte (Dissertation committee)
D'Esposito Mark, University of California Berkeley
Darlow Adam, Brown University
David SP, Brown University
Demiralp C, Brown University
Dou Wenwen, UNC Charlotte (Co-author)
Drury F, Rhode Island School of Design
Eran Mukamel, Harvard
Ernst LA, CMU
Fernbach Philip, Brown University
Fisher Brian, Simon Fraser University (Collaborator)
Flanigan T, Brown University
Forsberg AS, self-employed
Frank Michael, Brown
Fraser SE, Caltech
Ghoniem Mohammad, French University of Egypt (Co-author)
Gold, Joshua I., University of Pennsylvania
Goldin Gideon, Brown University
Goolkasian Paula, UNC Charlotte (Dissertation committee)
Gordon E, Brain Resource Company

Grant JE, Brown University
Green Tera, Simon Fraser University (Collaborator)
Grieve SM, Brain Resource Company
Grimm CM, Washington University
Gronchi Giorgio, University of Florence, Italy
Gunstad J, Kent
Hadjichristidis Constantinos, University of Trento, Italy
Hagmayer York, University of Göttingen, Germany
Hedrick TL, UNC Chapel Hill
Hoth KF, Brown University
Hughes JF, Brown University
Hung N, Brown Unbiversity
Hyun Dong Jeong, University of the District of Columbia (Co-author)
Iriarte-Díaz J, Brown University
Jackson CD, Aptima Inc.
Janjic JM, CMU
Jianu R, Brown University
Karelitz DB, Sandia
Keefe DF, University of Minnesota
Kosara Robert, UNC Charlotte (PhD advisor)
Kostandov M, Eureka Aerospace Corporation
Lagnado David, University College London
Lawrence J, Butler Hospital and Brown University
Lebrecht Sophie, Brown
Lee SY, Dartmouth Medical School
Lin JT, Brown University
Lombrozo Tania, UC Berkeley
Loriot GB, retired
Lu Aidong, UNC Charlotte (Dissertation committee)
Lucas Chris, UC Berkeley
Malloy PF, Butler Hospital and Brown University
Malt Barbara, Lehigh University
Marai GE, University of Pittsburgh
Miles J, Brown University
Miller DE, UCHSC
Moore DC, Brown University
Morel PA, University of Pittsurgh
Morley Nicki, Unilever Corporation
Navia B, Brown University
Nguyen V, Brown University
Niaura R, Brown University
Ochsner Kevin, Columbia University
Ombao Hernando, Brown
Over David, Durham University
Oztekin Ilke, Brown
Park Ju-Hwa, Brown University
Paul RH, University of Missouri St Louis
Pelcovits RA, Brown University
Pogun S, Ege University (Raphael)
Pollard Nancy, Carnegie Mellon University (Co-author)
Ribarsky William, UNC Charlotte (Employer)
Rips Lance, Northwestern University
Riskin DK, Brown University
Ritz A, Brown University

Robert Barretto, Columbia Univ
Salloway SP, Brown University
Salomon AR, Brown University
Schulz SC, University of Minnesota
Shakhnarovich G, Toyota Technological Institute at Chicago
Sheridan Margaret, Harvard University
Simon JH, Portland VA Hospital
Slavin VA, Lockheed Martin
Solomon Marjorie, UC Davis
Srinivas M, CMU
Stebbins G, Brown University
Suma Evan, University of Southern California (Co-author)
Swartz SM, Brown University
Sweet L, Brown University
Tashima K, Kochi Medical School
Tate DF, Brigham and Women's Hospital
Taylor G, University of Missouri St. Louis
Taylor LE Miriam Hospital and Brown University
Turkey BJ, Brown University
Turner MS, University of Pittsburgh
Ulin SP, Brown University
Voorn T, Hageveld
Wagner Anthony, Stanford University
Waldmann Michael, University of Göttingen, Germany
Walsh Clare, University of Plymouth UK
Wartell Zachary, UNC Charlotte(Co-author)
Weiss AP, Brown University
Willis DJ, University of Massachusetts Lowell
Wolfe SW, Hospital for Special Surgery
Yang Jing, UNC Charlotte(Co-author)
Yu K, Brown University
Zhang S, Mississippi State University
Zhou W, Brown University
van't Wout Mascha, Brown University

PROJECT SENIOR PERSONNEL

Laidlaw, David, Brown University
Badre, David, Brown University
Sloman, Steven, Brown University
Drury, Fritz, Rhode Island School of Design
Ziemkiewicz, Caroline, Brown University
Schnitzer, Mark, Stanford University
Law, Jeff, Stanford University

SINGLE COPY DOCUMENTS

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 10-1

NSF 10-564 **09/10/10**

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

IIS - EXPERIMENTAL EXPEDITIONS, (continued)

FOR NSF USE ONLY

NSF PROPOSAL NUMBER

1064261

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
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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 **Collaborative Research: Cognitive Optimization of Brain-Science Visual-Analysis Tools**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ **4,099,185**	**60** months	**01/01/12**	

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.1.e)
☐ 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 **FWA#00004460**
Exemption Subsection _____ or IRB App. Date **Pending**
☐ 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 POSTAL ADDRESS
Box 1910
Providence, RI 02912
United States

PI/PD FAX NUMBER
401-863-7657

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 **David Badre**	**DSc**	**2005**	**401-863-2777**	**David_Badre@brown.edu**
CO-PI/PD **Steven A Sloman**	**PhD**	**1990**	**401-863-7595**	**Steven_Sloman@brown.edu**
CO-PI/PD				
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, lobbying activities (see below), responsible conduct of research, 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 10-1). 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 disclosed 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

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AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME **Michael A Kostyshak**	**Electronic Signature**	**Sep 10 2010 9:19AM**

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER
401-863-9328	**Michael_Kostyshak@Brown.edu**	**401-863-7292**

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COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

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☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **Collaborative Research: Cognition-aware Visual Analytics of Brain Circuits**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ **323,634**	**60** months	**01/01/12**	

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

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☒ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date **04/08/10**
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PI/PD DEPARTMENT
Biological Sciences / Applied Physics

PI/PD FAX NUMBER
650-723-6132

PI/PD POSTAL ADDRESS
Clark Center Laboratories
Mail Code 5435
Stanford, CA 94305
United States

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME **Mark J Schnitzer**	**PhD**	**1999**	**650-725-7438**	**mschnitz@stanford.edu**
CO-PI/PD				
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CERTIFICATION PAGE

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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 disclosed to NSF.

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(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.
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AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME **Mary Grace Tecson**	**Electronic Signature**	**Sep 10 2010 4:39PM**

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER
650-725-7753	**mtecson@stanford.edu**	**650-498-4167**

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COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

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CCF - EXPERIMENTAL EXPEDITIONS

Collaborative Research: Cognitive Optimization of Brain-Science Visual-Analysis Tools

David H. Laidlaw (PI), Caroline Ziemkiewicz, Brown University Computer Science;
Steven Sloman (Co-PI), David Badre (Co-PI),
Brown University Cognitive, Linguistic, and Psychological Sciences;
Mark Schnitzer (Co-PI), Stanford Biological Sciences and Applied Physics and
Investigator of the Howard Hughes Medical Institute;
Jeff Chi-Tat Law, Stanford Biological Sciences;
Fritz Drury, Rhode Island School of Design

We propose a research agenda blending cognitive science, neuroscience, and human-computer interaction to study and improve interactive tools for facilitating scientific analysis. We believe knowledge of human cognition is now at a level where it can effectively inform the design of interactive computer tools. We will develop a driving software application for brain scientists to study connections within the brain and use it as a testbed for new interaction techniques, new visualization techniques, and analysis of these techniques. The software will support the reasoning process by gathering and managing data about networks and connections; gathering and managing imaging and experimental data; providing interactive mechanisms for visually selecting and analyzing portions of the data; and explicitly capturing, recording, and documenting users' scientific reasoning. Further, we will instrument the testbed to capture usage information and analyze the underlying cognitive state of users according to different hypothesized models of cognition. Some models will capture principles of cognition and perception, others will explicitly relate user actions and computer events, and still others will likely operate at more abstract levels. One of our targeted contributions is a mechanism for uniformly incorporating models at these different levels of abstraction into our testbed.

We hypothesize that the cognitive modeling will ultimately allow us to evaluate techniques in simulation, greatly speeding and at least partially automating the development of new and effective techniques. Beyond human computer interaction, we expect to make discoveries about cognition and which cognitive models are appropriate under different conditions. We also expect to enable our brain science collaborators to to make faster scientific progress in their study of connections in the brain at various scales.

The proposed work is timely because cognitive models appear to have almost reached a level at which they can make relevant predictions. Cognitive modeling of reasoning and analysis is also reaching towards neuron level understanding, which we believe will accelerate brain science significantly. Our group is particularly well poised to attack the area we propose because our expertise covers the multiple disciplines necessary, we are a small enough group to be nimble, and we have a track record of successful collaboration.

The proposed work has the potential to be transformative by bringing together several disciplines to create a new nexus of research. From this nexus we anticipate results will emerge much more quickly than they would via more traditional disciplinary approaches. The ability to automatically evaluate user interface effectiveness would be perhaps the most transformative element of the proposal. If successful, it would be broadly applicable.

Intellectual Merit The intellectual merit of this project is threefold. First, computer scientists will advance their understanding of how humans interact with computers at the cognitive and perceptual level and how such interactions can be improved. Some automation of the development of effective techniques is expected and would be transformative. Second, we anticipate advances in the understanding and modeling of human cognition from our cognitive modeling evaluation and experimentation. Third, the proposed infrastructure will enable brain scientists to advance their research agendas more efficiently and more quickly by incorporating information from a broader set of sources into their scientific reasoning.

Broader Impact. This project will provide practical experience with highly interdisciplinary research under to graduate students, postdoctoral scholars, and undergraduates. Because the tools will be made widely available, they will potentially benefit the entire brain science research community. Many other disciplines study linked types of data – gene regulation, protein signaling and even crime and terrorism analysis – all have the potential to benefit. In fact, almost any human-computer interface that involves reasoning has the potential to be improved by results from this research. Finally, the process of designing and developing effective interfaces for any human-computer application may well be broadly improved.

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*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.

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References Cited		
Biographical Sketches (Not to exceed 2 pages each)	2	
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Current and Pending Support	0	
Facilities, Equipment and Other Resources	0	
Special Information/Other Supplementary Docs/Mentoring Plan	1	
Appendix (List below.) **(Include only if allowed by a specific program announcement/ solicitation or if approved in advance by the appropriate NSF Assistant Director or designee)**		
Appendix Items:		

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Collaborative Research: Cognitive Optimization of Brain-Science Visual-Analysis Tools

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a Overarching Vision and Goals

We propose to apply concepts and models of cognition and perception to the development, evaluation, and optimization of computer interfaces for scientific inquiry. We will include not only scientific models of cognition and perception, but also those developed over centuries by artists and visual designers. Artists phenomenological understanding of the response of viewers to stimuli captures behavior that some scientific models miss, and we propose to codify it to influence interface designs.

To achieve this vision, we propose to:

- develop an interactive analysis and reasoning software tool for brain scientists to explore and analyze connectivity in the brain via imaging data, published literature, and other experimental data
- instrument the tool to create a testbed for new interaction and visualization techniques
- capture data of scientists use the tool, including interaction hardware events, video of body motion and body language, and tracking of eye fixation
- manually analyze captured data as training and evaluation data for subsequent modeling
- create a software framework for comparing captured data with models and principles from cognition, perception, and art
- evaluate a series of cognition and perception models and principles for their ability to predict user performance
- using feedback from brain scientists, define improved visualization, interaction, and analysis techniques
- iteratively optimize these new techniques using predictions from the cognition and perception models and principles
- validate the approach by confirming predictions empirically
- integrate our research efforts with several Brown classes
- make publicly available our captured user interaction data, our modeling testbed, and the brain-connectivity visual-analysis software

a.1 Overview, Background, and Significance

The following sections outline our rationale and motivation for the elements of our proposed research. They also sketch some of the preliminary results that have helped us architect the research and provided us with some confidence about some of the riskier aspects. A limited overview of related work is also included, although many citations have been removed to meet the two page limit.

Need for Software for Visual Analysis of Brain Connectivity The target user community for our analysis software is brain scientists studying the architecture and function of the human brain. Three of the four labs involved in this project are a part of this community.

The software we propose will support the reasoning process by gathering and managing data about networks and connections; gathering and managing imaging and experimental data; providing interactive mechanisms for visually selecting and analyzing portions of the data; and explicitly capturing, recording, and documenting users' scientific reasoning.

The human brain is one of the most complex organ in our body. It contains billions of neurons that form interconnected networks at different scales, from small networks with tens of neurons to large networks

with long-range connections that span across multiple brain areas. These neural networks are thought to subserve many important functions, from perception and cognition to learning and memory. However, our understanding of the neural basis underlying these brain functions are limited for the following reasons. First, a brain area typically receives both external inputs from other brain areas and internal inputs from within the same area. The input fibers from these two sources are both dense and intermingled. Therefore, it is very difficult to study the connectivity and dynamics of neural circuits in intact brain. Second, because brain wiring is extremely complex, researchers often finds it difficult to interpret the data without the help of software tools.

Recent advances in molecular and imaging techniques have opened new possibilities in studying neural connectivity in intact brain. These studies use magnetic resonance imaging or fluorescence microscopy to trace neural connections and provide increasingly detailed information about neuronal wiring from within and between brain areas. Such information is extremely valuable because it allows researchers to study how information from external areas is transformed by intrinsic circuits in a brain area to generate new outputs. However, the amount of data generated from these studies only exacerbates the problems in data analysis. Furthermore, most neuroanatomy software systems display only either external (between brain areas) or internal (within a brain area) connection data. In order to fully understand the function of cortical circuits, we need an interactive visualization tool that displays both internal and external connectivity and allows the user to reduce the complexity by filtering out irrelevant information.

Understanding neural circuits and their function has potentially far-reaching implications in science, medicine, and engineering. The proposed visual analysis tools would have an immediate impact on neuroscience research in interpreting circuits connections that might underlie different aspects of brain function. They also provide a convenient framework for comparing neural connectivity in normal and diseased brains, thus could be used to diagnose neurological diseases and evaluate treatments. In addition, understanding the computational principles that underlie higher brain functions, such as attention, decision formation, learning, and memory, would aid design of artificial intelligence systems. The annual neuroscience meeting draws tens of thousands of researchers studying the brain. A substantial portion of them study networks within the brain directly or would benefit from better understanding collectivity in the context of their research problems.

We illustrate the needs with an example from the Schnitzer laboratory at Stanford. A research direction there is the study of neural circuits that underlie sensorimotor learning. A brain area that they are interested in is the prefrontal cortex, which is a polymodal area that receives sensory and reward signals from multiple sources and sends outputs to many cortical and subcortical motor structures to guide behavior. It is suggested that sensorimotor learning occurred as a result of changes in sensory-motor mapping that occurs within the local circuits in the prefrontal cortex.

To form hypotheses about the precise location at which learning occurs, it is important to consider simultaneously the external and internal connections. The visual analysis tools proposed would be particularly useful for this reasoning process because, as opposed to traditional brain visualization tools, it will allow simultaneous visualization of connectivity at multiple levels. The user can, as a result, visualize interactions between external and internal circuits in a common visual framework. The reasoning process can further be aided by selective filtering of irrelevant information (e.g. inputs from auditory cortex in a visual task), and post-hoc reevaluation of the visual reasoning process. This workflow was captured in [1] and is shown in Fig. 1.

Related Work in Systems for Assisted Analysis Traditionally, visualization enables humans to understand data by representing it visually. More recently, interest in other fundamental visualization issues has emerged. Among others, *Illuminating the Path* [2] was written in the context of growing intelligence needs after 2001 and defines the new field of visual analytics as the science of analytical reasoning facilitated by interactive visual interfaces. In addition to defining the term, the booklet establishes the value of such research in the context not only of homeland security but also of any field that involves analysis of complicated and large data.

Recent work in visual analytics can be broadly separated into two categories: theoretical research based on existing cognitive studies and applied work. The proposed work is intended to complement existing

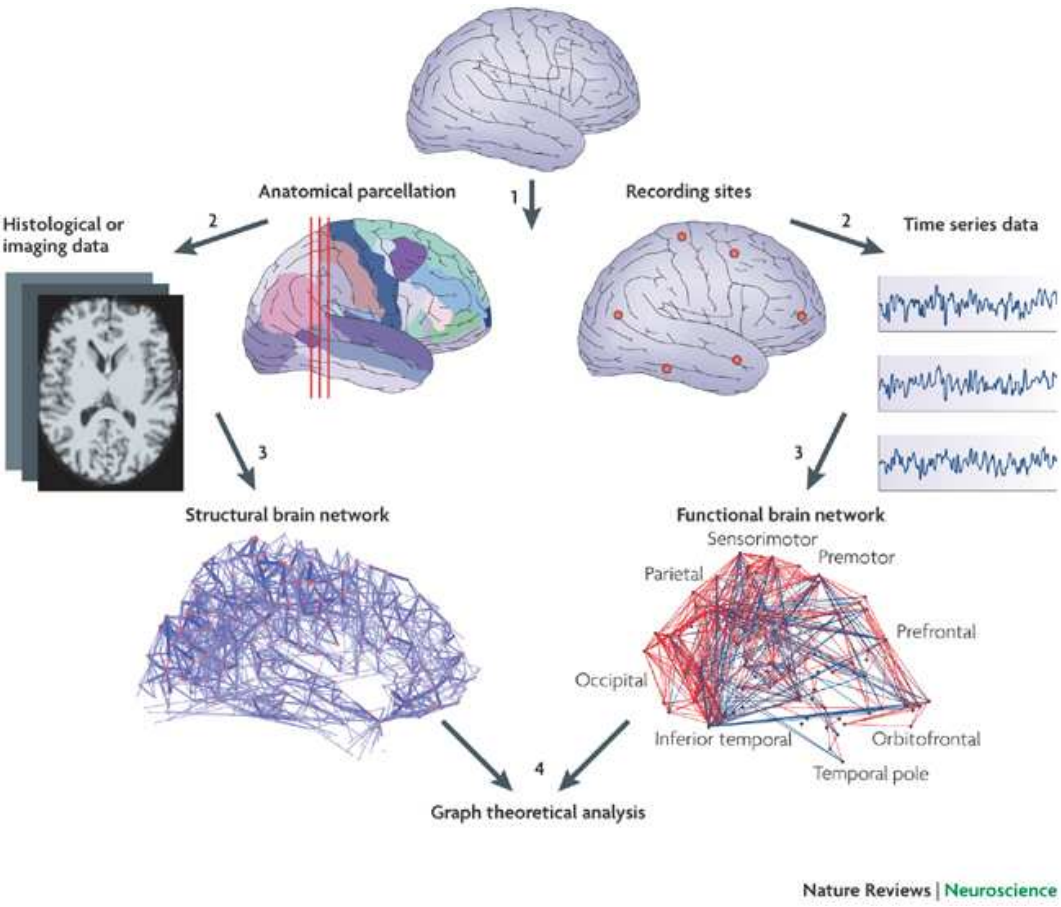

Figure 1: An example of the multi-level workflow of brain network analysis (from [1]).

research with low-level task information specific to the proposed domain. The collaborative nature of this proposal will enable us to gather and interpret data from real-life scientific analysis which can both link theoretical research to real applications and capture and quantify analysis dimensions that are hard to track in artificial settings (e.g., psychological factors such as drive or boredom or long-term temporal effects on analysis).

Much of the applied work has been developed and evaluated in the context of intelligence analysis, and as such deal with textual information, large volumes of documents, and temporal or geographic data. Also, few of the systems explore the full range of cognitive principles, ground their design in theoretical and empirical evidence, or aim for thorough evaluation. Most systems don't go beyond the concepts of hypothesis and confirming or disconfirming evidence to structure analysis; they don't aim to convincingly demonstrate that the employed techniques facilitate better analysis either in terms of results or an improved analysis behavior in accordance to normative guidelines. The proposed work has the opportunity to bridge the gap between theory and practice by joining cognitive scientists, visualization experts, and domain specialists ensuring that relevant principles from cognitive psychology are used to design visualization mediums that can be evaluated in concrete scientific settings, with measurable results. No approach we have seen aims to link a visualization workflow to a decisional workflow, which is what we propose in this process.

Related Work in Circuitry and Network Exploration Network visualization in the domain of brain connectivity is still in its infancy. A few of the online databases hosting connectivity information have developed their own visualization modules. Others have developed personalized visualizations for specialized brain regions or organisms [3]. Finally, in [1] the authors discuss the opportunity of approaching brain

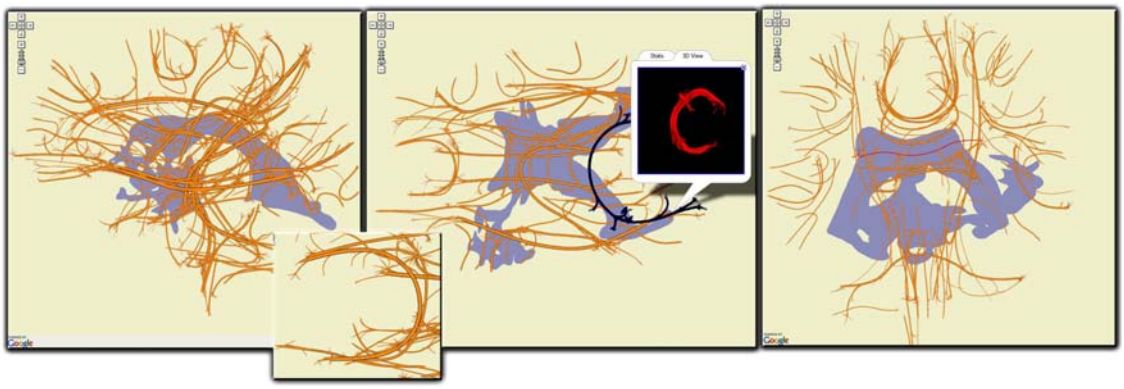

Figure 2: DTI tractography data projected onto the transverse, coronal and sagittal planes. Major tract bundles are represented schematically by their centroid tract; individual tracts in bundles are linked from the centroid bundle to their projected end-points. Bundles can be selected and pre-computed statistical data along with 3D poses of the tract bundle can be displayed.

connections from a graph theoretic perspective. These approaches have several drawbacks: they fail to adequately merge findings from network visualization with neuroscientists' intuition; they are limited in scope to singular organisms, brain regions, or connection databases; they don't allow users to integrate their own experimental data into the analysis; and they don't offer analysis features such as load/save capabilities, or hypothesis-formation support. We propose to address these limitations.

Preliminary Results in Developing Visual Analysis Tools for Science at Brown Over the last decade, we have developed scientific visualization tools that have taught us a number of lessons about science and about developing tools to support it. Our experience provides us a solid foundation of knowledge, laboratory culture, and infrastructure for attacking the proposed problem. In this section we describe a few examples of software we have created and lessons we have learned that we believe will be instrumental to our proposed work.

Brooks describes the principles of such work much better than we can in his paper "The Computer Scientist as Toolsmith II"[4]. A central message is that, "hitching our research to someone else's driving problems, and solving those problems on the owners' terms, leads us to richer computer science research." While there are costs to this sort of approach, there are also benefits; our work has followed this philosophy with good results.

Our experiences with network visualization will help in developing the multi-scale circuit diagramming components of the proposed work. We have studied the workflow associated with protein-interaction networks analysis in the context of high-throughput protein activation experimental data. Proteomic researchers conduct experiments revealing the degree of activation of proteins and wish to relate this data to the body of documented protein interactions from the literature [5]. Linked views of the signaling network and experimental data, and quick access to the literature and to database information about the proteins and signaling should apply to brain circuit analysis tools. Fig. 4 illustrates an interactive system created during this research.

Our experience with developing more imaging-oriented applications will help with the components of the proposed work that deal with microscopy and MRI data. Some representative examples include 3D flow visualization [6; 7; 8; 9; 10], diffusion MRI visualization and analysis [11; 12; 13], carpal kinematics analysis [14; 15; 16], and even archeology visual analysis [17]. In particular, Fig. 2 and Fig. 3 show tools for studying imaging and connectivity data derived from diffusion MRI.

Finally, Brown's proximity to RISD provides a wealth of visual design expertise from not only the students but also the faculty, one of whom is an investigator on this proposal. Laidlaw and Drury have taught a "Virtual-Reality Design for Science" class several times, bringing together computer science students, art

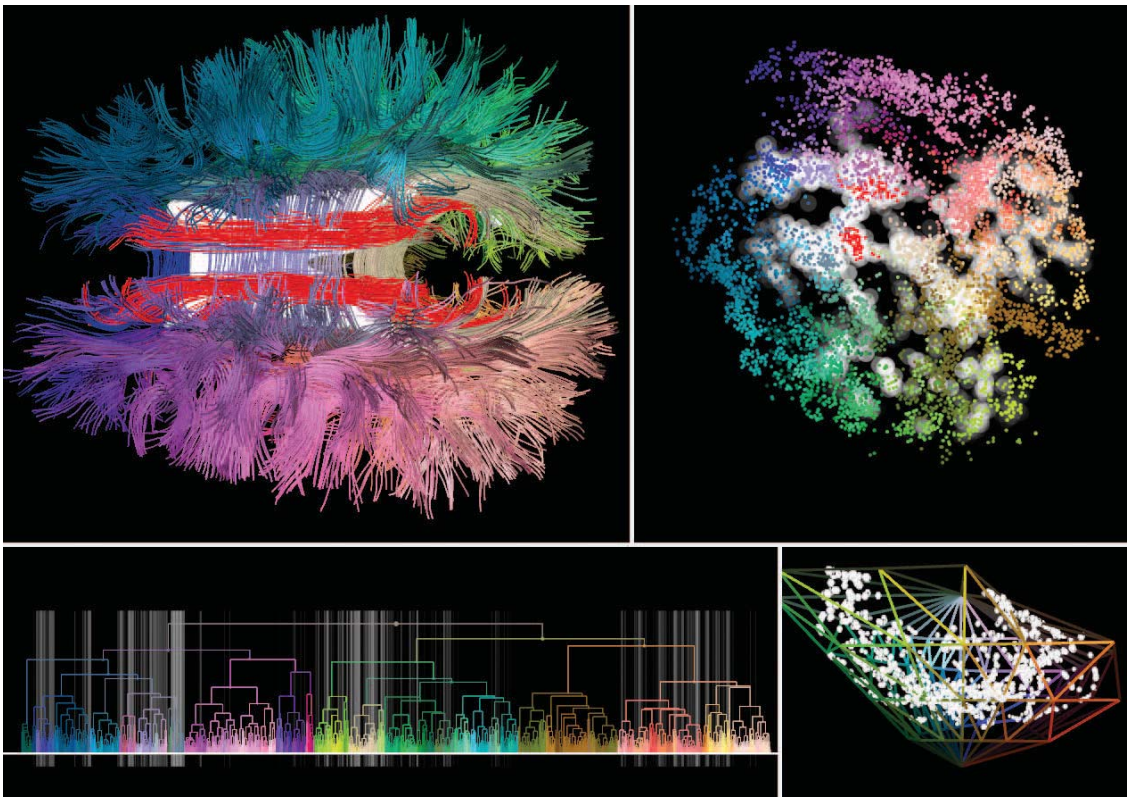

Figure 3: Coordinated DTI tractogram model exploration in lower dimensional visualizations: 2D embedding (upper-right), hierarchical clustering (lower-left), and L*a*b* color embedding (lower-right). A selection of a tract bundle (red) in the hierarchical clustering is mirrored in the other views.

students, and scientists to explore the process of designing visual and interactive tools to accelerate science. We have documented some of what we have learned in the literature [18; 19; 20; 21].

Preliminary Results in Capturing and Analyzing User-Interaction Data Laidlaw's lab has been one of the leading visualization labs in formal evaluation of visualization methods [22; 23; 24; 25]. Some of these evaluations were done in collaboration with perceptual psychologists from Sloman and Badre's department. They incorporated some of the kinds of experimental design issues that will be needed to execute our proposed work. Interestingly, these formal evaluations and the "critiques" of of our Brown/RISD class are related – in a sense, they are attempting to solve the same problem of understanding how humans and software interact effectively. This synergy is fascinating and enlightening, but unfortunately rare. We will leverage it in the proposed work.

Overview of Models and Principles of Cognition and Perception A goal of this project is to improve user performance on brain circuit analysis and other analysis tasks by identifying design principles for computer interfaces that are well aligned with user workflow, including cognitive reasoning and decision-making. If we can predict how users will engage with our software, we can effectively refine its design. A major consideration when undertaking this predictive modeling task is that human actions must be analyzed across many orders of magnitude of time.

In [26], Anderson argues that we can build successively longer "bridges" across these time scales in understanding, for example, how low-level actions of a student (e.g. eye-tracking across a sheet of paper or computer display) cascade into long-term educational influences. We will support this kind of cascading for analysts using our tool, and will draw on previous research in cognitive modeling architectures in addressing interaction analysis at these multiple time scales. Much of this past research has attempted to create

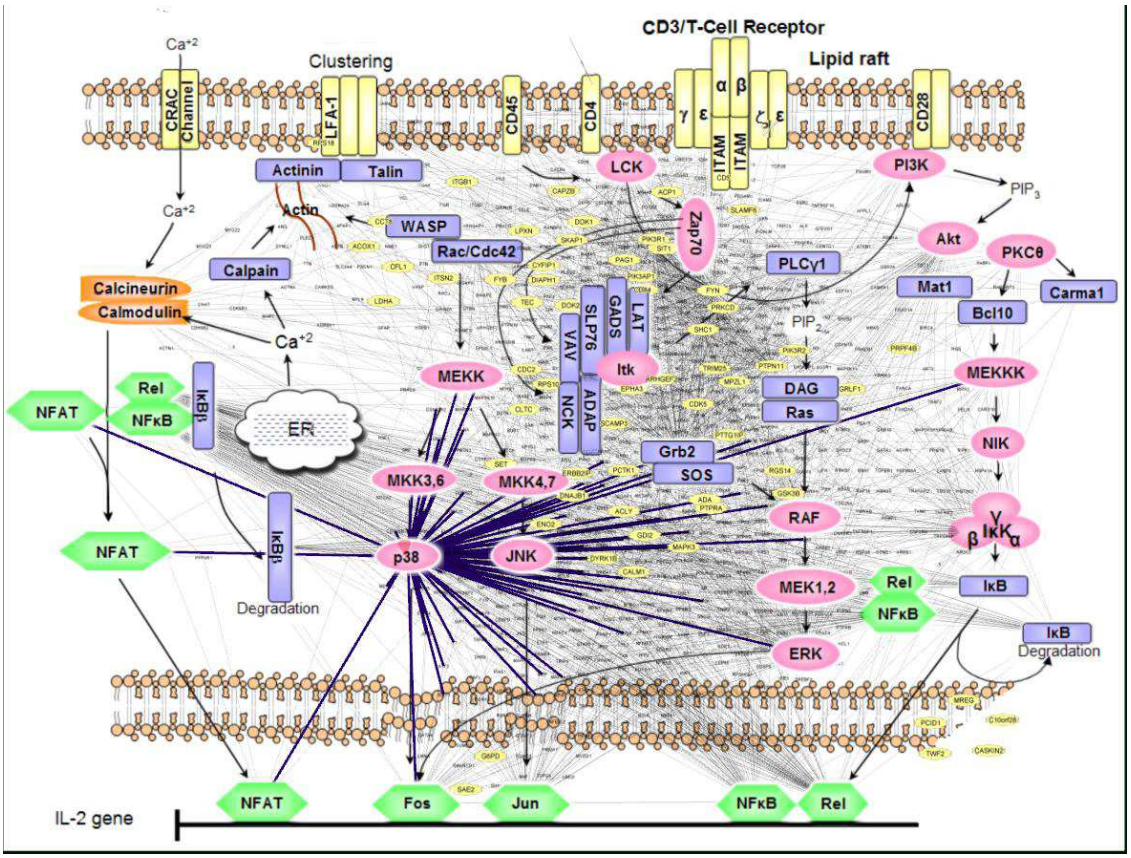

Figure 4: Proteins and interactions extracted from the Human Protein Reference Database are integrated into a stylized signaling pathway model.

models that predict the performance time of an average user completing a unit task using a proposed user interface. In Project Ernestine [27], for example, researchers showed that a CPM-GOMS cognitive analysis using explicit hierarchical knowledge of user goals and actions can predict user performance on tasks with high accuracy. These predictions were used in evaluating the design of workstation upgrades for telephone operators. Surprisingly, this remains one of the canonical examples of such predictive models. At a lower level, Gluck developed a model (in ACT-R/PM) that predicted student performance on algebra problems based on the distribution of eye movements observed during eye-tracking [28]. These findings support the notion that learning and complex reasoning may be decomposed into small scale, primitive actions, and that we should account for these in our own analysis of user interactions.

As examples, we describe three principles that will be used in our research. First, principles of perception and attention will determine the physical parameters of the display. Second, principles of goal selection will determine the number of tasks made available to the user and their accessibility at any point in time. Third, principles of judgment and reasoning will determine the design of the tool, the information that is on display at any given time, the actions that it makes easy, and the guidance and feedback that it provides.

The Principles of Perception

The software will make available facilities for viewing data, like the network itself, and for performing other tasks (e.g., maintaining history, calculation facilities, note-taking facilities). The designers will have to make decisions about how to display the data (e.g., number of network graphs, network parameters, number of nodes per network) and the number of other functions to include in the display. Note that these are all dynamic entities. They change rapidly over time and they interact constantly.

Recent work in the study of attention has examined the number of objects that can be tracked at any given

time [29] and the physical parameters that determine the identity of an object [30]. These studies present participants with a large number of objects moving in either random or systematically varying directions on screen. Participants' task is to track one or more of the objects; i.e., to maintain the identity of some number of objects as they move about. In some experiments, the objects disappear or become occluded or change in color or size. These experiments reveal the key physical parameters describing how people deploy and distribute attention to maintaining awareness of the existence and behavior of objects as they change over time. From this work, and from older work on the capacity of attention [31], we can draw inferences about how networks should be drawn, the number of nodes and links that should be displayed, and how much changing information about the network can be maintained simultaneously.

Goal Maintenance

Scientific problem solving entails multitasking. The scientist must decide what to look at, recognize patterns in the data, decide which hypotheses to test and actually test them, all the while keeping track of what has been investigated, what has not, any new ideas that come to mind while exploring, while also being mindful of their other everyday concerns. Research has studied the process of multitasking using a variety of paradigms including prospective memory [32], task switching [33] and goal priming [34; 35].

Several principles have emerged from this work identifying the conditions under which different goals facilitate versus compete with one another. Goals facilitate when they share a larger purpose. For instance, sub-goals of a single task tend to facilitate one another. Goals also facilitate one another when the task performed to pursue them are similar. Otherwise, goals compete. Relations among goals also determine whether they should be pursued simultaneously or sequentially. We will use these principles to determine which tasks to make easily accessible to users and which to put in the background. Moreover, people differ in their ability to juggle multiple pursuits simultaneously. Our system will tune itself to individuals' work styles.

Hypothesis Testing and Problem Solving

We will also incorporate higher level cognitive concepts as illustrated by the following three examples. First, the software will be designed to identify and mitigate a number of human foibles in hypothesis testing and problem solving. Such foibles include failing to consider alternatives and interpreting data in a way that supports prior hypotheses. Second, we will leverage the cognitive principle of causal reasoning [36]. Third, dual-system theory, which distinguishes subconscious intuitive responses from more conscious, deliberate, and deliberative responses, will lead to different parallel components of our interfaces.

Overview of a Software Framework for Modeling Interaction At the heart of our research is a software framework that will use a particular model or principle to predict user performance. This framework will provide to software modules a description of the model or principle, a description of the user interface, and a description of user goals; the software modules will produce probabilistic estimates of the state of a user over time predicted by the model.

Modules that implement cognitive or perceptual performance can be coupled and compared within the framework. Because each such module has a common interface, the system can be easily extended to include new modules. A supervisor module can access predictions from all relevant modules and assemble the results into an overall prediction. It can also compare the results to acquired user performance data to establish contexts in which various models might be more or less appropriate.

We expect this core element to evolve significantly through the five years of the project. It cannot be meaningfully defined without the data we will acquire from users, so details beyond this overview are not possible yet.

Knowledge Transfer Our knowledge transfer efforts will include integration of this project with several courses at Brown, publication of research results, and distribution of the data we acquire and the software we develop. Several versions of the system will be deployed to the public as an open-source project via SourceForge, using their public license derived from the GNU General Public License. We have been using this approach for a virtual reality library that we are developing with other NSF support (OCI-09-23393). We will also provide binary installers for Windows and Mac so that scientist users can download and use our software. Releases will be advertised through blog postings, publications, direct contact, and during conference presentations in order to increase visibility among the larger visualization, human-computer

interaction, and brain science communities. We will also propose to teach tutorials and classes at conferences if there is interest. Additionally, researchers from the brain science labs will be encouraged to use the tool in classes and other educational settings in order to help students understand connectivity in an accessible visual form.

The system will include instructions and easy mechanisms for reporting bugs and providing other feedback. We will address serious maintenance issues as needed. Usage data will be gathered from users if they opt in upon downloading the tool; observation of the tool's use will be undertaken in the brain science labs involved in the proposal. These observations will be used to inform future iterations of the software.

a.2 Expedition Goals The proposed research directly addresses the goals of the Expedition Program as follows.

Goal: To catalyze research into deep scientific questions, hard problems, and compelling applications in CS-related areas.

Our work reaches far into three different research areas: human-computer interaction, cognitive modeling, and the study of connectivity in the brain. In human-computer interaction, a framework for predictive modeling of human interactions with computers has the potential to catalyze significant followon research in such models. The models we experiment with ourselves have the potential to accelerate others' research in user interface design not only in one scientific domain, but across many and likely outside of science as well.

Beyond computing, our proposed research addresses fundamental questions about how the brain works, from the level of cellular connections up to analytical reasoning.

Goal: To inspire pursuit of careers in CS and engineering.

The students and postdocs in this unusually interdisciplinary research will likely continue on in research careers that reflect some of the novel aspects of the work. The PI's experience with earlier interdisciplinary research projects is that they tend to attract students who are not attracted by more traditional computer science. Students interested in biology or visual design tend to be more diverse than those interested in computer science and engineering. Brown University also devotes considerable attention to creating an environment of diversity in its student population. The proposed work will be able to draw on that diversity.

The proposed work will also add significantly to two computer science courses at Brown that link education and research. One, "Interdisciplinary Scientific Visualization" centers around designing and executing research projects by emulating the US model of research design and funding. Students identify a research problem with a collaborator from another discipline, explore potential solutions, write a "funding" proposal, peer review the set of proposals, do the research, write it up, and present it all during one 13 week semester. They get a taste of the excitement, challenge, and risk inherent to interdisciplinary research in a context where the real risk is minimal. This class will serve as a first line of outreach for our proposed work, broadening exposure from the handful of students directly involved to a dozen or so each time it is taught. From past experience, we expect that some of these students will go on to participate actively in the proposed work or other research projects.

A second course that will benefit from this research is "Virtual Reality Design for Science." This course, jointly listed and taught at Brown and the Rhode Island School of Design, teaches design students enough science so that they can author new interactive tools for scientists. We plan to automate the process of evaluating these interfaces without going through the months-to-years implementation process, providing a demonstration of the acceleration our research will make possible

Goal: To stimulate research, education, and knowledge transfer that promise scientific, economic and other societal benefits.

Our plan to make the modeling testbed, the captured interaction data, and the interactive brain connectivity analysis software all widely available should effectively transfer knowledge into several scientific communities. Both binary and source distributions will be provided. The research and development that ultimately result using these resources should provide broad scientific benefits, as already described. Broader societal benefits that may result are difficult to predict specifically, but more effective ways for people to use computers has great potential.

a.3 Expedition Project Characteristics In addition to matching the Expedition program goals well, the project we propose has characteristics expected of expedition projects.

Characteristic: Foster creativity, informed risk-taking, and synergy.

Our project is creative in bringing together several disciplines and in advancing all of them. These coordinated advances, each dependent on elements from other disciplines, are indicative of an Expedition that is greater than the sum of its parts. Our research will continue a tradition of research creativity within and across the investigators' research groups. Our groups have already demonstrated that they value complementary and collaborative research, and Brown has a long tradition of blending education and research as effectively as any institution we know. If anything, we expect that the risk inherent to the work we propose and the environment we may build is beyond what reviewers will view enthusiastically. But we feel the risk is worth the potential rewards.

Characteristic: Draw upon well-integrated, diverse teams.

Our proposed work is structured around a vision that integrates all of the investigators – each is essential to the success of the project. The investigators' work is diverse; three different departments are represented by the four of us. Each brings unique abilities to the group. Although only one of us is formally in a computer science department, our vision is centered around a core computer science problem: understanding human computer interaction and applying that understanding.

Characteristic: Stimulate effective knowledge transfer.

We propose to spend significant effort to transfer knowledge across disciplines and outside of the immediate research group.

Characteristic: Demonstrate elements that enable discovery.

Our experimental data capture, cognitive modeling testbed, and brain connectivity analysis tools are directly targeted at enabling discovery.

b Leadership and Collaboration

We have assembled an excellent team for accomplishing the proposed research. We have recognized experts in cognitive science, neuroscience, computer science, and visual design. Their complementary expertise covers a breadth unusual in such a small group. The problem area of brain science and the research thrust of cognitive optimization of user interfaces are quite synergistic, which helps to reduce the number of disciplines necessary to attack the problem.

Importantly, the faculty investigators have been intellectually engaged with one another for some time. Badre and Sloman are in the same department and Sloman has attended one of Badre's classes. Laidlaw and Sloman are participants in an ongoing working group studying a dual-system model of cognition. Two of Sloman's Ph.D. students attended Laidlaw's "Cognition, Human-Computer Interaction and Visual Analysis" class last year, and one of Laidlaw's students attended two of Sloman's classes this year. Schnitzer provided the inspiration for attacking this problem by contacting Laidlaw several months ago, and they and their groups have been interacting since on what the neuroscience needs are. Laidlaw and Drury have been teaching a class "Virtual-Reality Design for Science" over the last seven years and have learned much about working collaboratively between the design of software and the design of visual and interactive artifacts. Drury has also participated in a number of perception oriented studies of visualization and interaction tools.

Brown provides a supportive environment for multidisciplinary work such as we propose. The diverse student body is creative, and we plan to leverage that by involving undergraduates in this research. Brown has porous disciplinary boundaries which permit easy collaboration. Brown's Brain Sciences Institute is an example of a multidisciplinary organization that leverages this easy collaboration; it also provides supportive infrastructure, including biological imaging, centralized talk announcements, small seed funding for new collaborations, undergraduate research opportunities, and multiple examples of successful collaborations. This institute also provides numerous brain scientists who may be interested in using and testing the tools that we will develop.

Two main factors helped ensure the success of this collaboration. The first factor is the group structure. The group is small, which limits the complexity of interactions. The group has a natural center of coordination in computer science, where the PI has been leading collaborative research efforts of similar scope for a

number of years. As described above, the group has already been collaborating for some time. The second factor is the well-defined set of deliverables and goals that will provide inspiration and deadline pressure.

Because of the relatively small size of the group, the management structure will be relatively simple. The PI, Laidlaw, will be responsible for monitoring the schedule and interacting with the other research lab leaders to ensure they are on track. Because the work is so interdependent, shared deliverables and dependencies will help to keep the research labs synchronized. A full-time postdoctoral scholar will help Dr. Laidlaw with this coordination. He has had excellent results with similar structures in past collaborations of the same scope.

c Experimental Systems and Shared Experimental Facilities

We will utilize some shared facilities in our research and will share software and data that we produce to allow further research by others.

Much of the proposed work requires facilities typical to each individual investigator, e.g., computers and laboratory space. We propose to acquire a few resources specific to this project including a pupil tracking system. We will also leverage a number of interaction and display devices already in place in Brown's computer science Department and Center for Computation and Visualization (CCV). These include tiled display walls, stereo-enabled desktop displays, an ultra-high-resolution Wheatstone stereoscope, haptic devices, and a virtual-reality cave expected to produce first light in late 2011. This NSF-funded cave will feature a 360 field of view, resolution close to the limit of human perception, and head tracked stereo imagery. It will be able to emulate displays of many different form factors because of its display properties.

We expect to produce a software testbed that will be used across the collaborators to test models of cognition and perception in the context of human computer interaction. If our modeling effort is successful, we expect to be able to distribute it so that software developers can benefit from the potential acceleration in developing effective interactive software. In addition, the software for brain scientists to analyze connectivity will be made available not only within our collaborative group but also to the scientific community. We expect that it will be broadly useful within the neuroscience and psychology communities.

In addition to the software systems, we will make available data captured from users of the testbed. These data will enable other researchers to pose their own models of interaction, visualization, cognition, or psychology and test them against human performance.

d Summary of Synergy

While admittedly risky, we believe that the proposed work would provide broadly valuable benefits to all the disciplines directly involved, to many other scientific disciplines, to software development and design, and to knowledge workers. The synergy of the group is outstanding. Though relatively small, it covers a surprisingly large range of disciplines. Although the group includes computer scientists, artists, psychologists, and neuroscientists, the shared goal of understanding the brain brings us all together. Research in each of the disciplines is advanced by the proposed work, so motivation to succeed is shared by all. No discipline can be removed without fundamentally changing the nature and reducing the scope of the overall research – the sum is greater than what any subset could accomplish.

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David H. Laidlaw

Professor
Computer Science
Brown University
Providence, RI 02912

Phone: (401) 354-2819
Fax: (401) 863-7657
Email:dhl@cs.brown.edu

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.
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Other Publications

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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.

Biographical Sketch: David Badre

Professional Preparation

B.S., 2000, University of Michigan, Biopsychology and Cognitive Science
Ph.D. 2005, MIT, Cognitive Neuroscience

Appointments

2008 - Assistant Professor, Cognitive and Linguistic Sciences and Psychology, Brown University
2005 - 2007 Postdoctoral Fellow, Helen Wills Neuroscience Institute, University of California, Berkeley
2004 - 2005 Visiting Scholar, Department of Psychology, Stanford University

Publications: Relevant to Proposal

Badre, D., Kayser, A. S., and D'Esposito, M. (2010) Frontal cortex and the discovery of abstract action rules. *Neuron,* 66, 315-326

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Badre, D., Hoffman, J., Cooney, J.W., and D'Esposito, M. (2009). Hierarchical cognitive control deficits following damage to the human frontal lobe. *Nature Neuroscience*, 12(4), 515-522.

Badre, D. (2008). Cognitive control, hierarchy, and the rostro-caudal axis of the prefrontal cortex. *Trends in Cognitive Science*, 12(5), 193-200.

Badre, D. and D'Esposito, M. (2007). FMRI evidence for a hierarchical organization of the prefrontal cortex. *Journal of Cognitive Neuroscience*, 19(12), 2082-2099.

Other Publications:

Öztekin, I., Long, N. M., and Badre, D. Optimizing design efficiency of free recall events for fMRI. *Journal of Cognitive Neuroscience*. In Press.

Badre D., and Wagner, A. D. (2007). Left ventrolateral prefrontal cortex contributions to the control of memory. *Neuropsychologia*. 45, 2883-2901.

Badre, D. and Wagner, A. D. (2006). Cognitive and neurobiological mechanisms underlying cognitive flexibility. *Proceedings of the National Academy of Sciences, USA*, 103(18), 7186-7191.

Badre, D., Poldrack, R. A., Paré-Blagoev, E. J., Insler, R., and Wagner, A. D. (2005). Dissociable controlled retrieval and generalized selection mechanisms in ventrolateral prefrontal cortex. *Neuron*, 47, 907-918.

Badre, D. and Wagner, A. D. (2005). Frontal lobe mechanisms that resolve proactive interference. *Cerebral Cortex*, 15(12), 2003-2012.

Synergistic Activities

1) I have developed two courses at Brown that I teach on a routine basis and that are attended by students outside of my immediate department. These are an introductory survey course in Introduction to Cognitive Neuroscience, and an upper level course in functional magnetic resonance imaging methods. The latter course in particular could benefit from additional software applications that will help classroom participation and learning.

2) I am on the editorial board of the journal Cognitive Neuroscience. As a member of the founding board, I've had a role in shaping the direction of that journal.

3) I am an ad hoc reviewer for *Biology Letters (formerly section of Proc. R. Soc. B), Brain and Language,Cerebral Cortex, Cognition, Cognitive, Affective, and Behavioral Neuroscience, Cognitive Neuropsychology, Cognitive Neuroscience, Cognitive Psychology, Experimental Brain Research, European Journal of Neuroscience, Human Brain Mapping, Journal of Cognitive Neuroscience, Journal of the International Neuropsychological Society, Journal of Neurophysiology, Journal of Neuropsychology, Journal of Neuroscience, NeuroImage, Neuron, Neuropsychologia, Neuroscience, Neuroscience Letters, Neuroscience & Biobehavioral Reviews, PLoS ONE, Proceedings of the National Academy of Sciences, USA, Psychological Science, Psychological Bulletin, Psychonomic Bulletin & Review, Social, Cognitive, and Affective Neuroscience, Science, Topics in Cognitive Science, Trends in Neurosciences*; in addition to the NSF Perception, Action, and Cognition and Cognitive Neuroscience panels, the Neurosciences and Mental Health Board, MRC (UK), and the Wellcome Trust (UK).

4) This year, I am co-organizer and co-chair of a symposium on the interaction of cognitive control, decision making, and memory at the upcoming Memory Disorders Research Society meeting in October, 2010.

5) I have served on the colloquium organizing committee for both the Departments of Cognitive and Linguistic Sciences and the Department of Neuroscience at Brown, and so have helped to organize those speaker series in order to enhance the educational experience of students, faculty, and staff in both departments.

Collaborators and Co-Editors

Michael Frank (Brown), *David Laidlaw* (Brown), *Hernando Ombao* (Brown), *Marjorie Solomon* (UC Davis), *Cameron Carter* (UC Davis), *Randy Buckner* (Harvard University), *Kevin Ochsner* (Columbia University), *Margaret Sheridan* (Harvard University), *Martin Albert* (Boston VA), *Mark D'Esposito* (University of California, Berkeley), *Anthony Wagner* (Stanford University).

Graduate Advisors and Postdoctoral Sponsors

Anthony Wagner, Department of Psychology, Stanford University

Mark D'Esposito, Department of Psyhcology, University of California, Berkeley

Thesis Advisor and Postgraduate Scholar Sponsor

Anthony Wagner, Department of Psychology, Stanford University

Postdoctoral Fellows

Current: *Ilke Öztekin* (NYU, PhD in 2008)

Students

Current Graduate Student: *Jennifer Barredo*; Committee Member: *Elizabeth Chrastil, Sophie Lebrecht, Bradley Doll, Adam Darlow, Heida Sigurdardottir (Neuro), Arjun Bansal (Neuro), Kaivon Paroo (Neuro), Hakmook Kang (Biostats).*

STEVEN A. SLOMAN

Professional Preparation

Undergraduate institution: University of Toronto, Psychology, B.Sc., 1986
Graduate Student: Stanford University, Psychology, Ph.D., 1990
Postdoctoral fellow: University of Michigan, Cognition and Perception, 1990-1992

Appointments

2005- Full Professor, Brown University
1998-2005 Associate Professor, Brown University
1992-1998 Assistant Professor, Brown University

Publications

(1) Five most closely related to proposed project:

Fernbach, P. M., Darlow, A. & Sloman, S. A. (in press). Neglect of alternative causes in predictive but not diagnostic reasoning. Psychological Science.

Darlow, A. & Sloman, S. A. (in press). Two systems of reasoning: Architecture and relation to emotion. Wiley Interdisciplinary Reviews Cognitive Science.

Fernbach, P. M. & Sloman, S. A. (2009). Causal learning with local computations. Journal of Experimental Psychology: Learning, Memory, and Cognition, 35, 678-693.

Sloman, S. A., Barbey, A. K. & Hotaling, J. (2009). A causal model theory of the meaning of *cause*, *enable*, and *prevent*. Cognitive Science, 33, 21-50.

Sloman, S. A. (2005). Causal models: How we think about the world and its alternatives. New York: Oxford University Press.

(2) Five additional publications:

Hagmayer, Y. & Sloman, S. A. (in press). Decision makers conceive of themselves as interveners, not observers. Journal of Experimental Psychology: General.

Barbey, A. K. & Sloman, S. A. (2007). Base-rate respect: From ecological rationality to dual processes. Behavioral and Brain Sciences, 30, 241-254.

Sloman, S. A. & Hagmayer, Y. (2006). The causal psycho-logic of choice. Trends in Cognitive Sciences, 10, 407-412.

Sloman, S. A. & Rips, L. J. (Eds.) (1998) Similarity and symbols in human thinking, Cambridge: MIT Press book.

Sloman, S. A. (1996). The empirical case for two systems of reasoning. Psychological Bulletin, 119, 3-22.

Synergistic Activities

- Associate Editor, Cognition, 2006-
- Associate Editor, Memory and Cognition, 1998-2001.

- Robert J. Glushko Distinguished Visiting Scholar in Cognitive Science, University of California, Berkeley, 2009.
- Joint project on communicating with public about social issues with the firm Cultural Logic, 2004-2006.
- Development of tool to run psychological experiments on the internet with Brown's Scholarly Technology Group.

Collaborators and Other Affiliations

(1) Collaborators

Barbey, Aron, NIH
Bes, Benedicte, University of Toulouse II, France
Bonnefon, Jean-Francois, University of Toulouse II, France
Evans, Jonathan, University of Plymouth, UK
Gronchi, Giorgio, University of Florence, Italy
Hadjichristidis, Constantinos, University of Leeds, UK
Hagmayer, York, University of Göttingen, Germany
Lagnado, David, University College London
Lombrozo, Tania, UC Berkeley
Lucas, Chris, UC Berkeley
Malt, Barbara, Lehigh University
Over, David, Durham University
Walsh, Clare, University of Plymouth, UK

(2) Graduate and Post-Doctoral Advisors

Gordon Bower (Stanford University)
Lance Rips (Northwestern University)
David Rumelhart (inactive)
Amos Tversky (deceased)
Edward E. Smith (Columbia University)

(3) Thesis Advisor and Postgraduate-Scholar Sponsor

Postdoctoral Sponsor: Silvia Gennari, David Lagnado, Emanuel Robinson, Mascha van't Wout, Clare Walsh
Thesis Advisor: Adam Darlow, Philip Fernbach, Gideon Goldin, Ju-Hwa Park, John Santini, Joanna Tai.

Total number of graduate students advised: 6
Total number of postdoctoral scholars advised: 5

Biographical Sketch

Caroline Ziemkiewicz
Researcher
Charlotte Visualization Center
9201 University City Blvd
Charlotte, NC 28223
980 322 3413
cziemki@gmail.com
http://viscenter.uncc.edu/~caziemki

A. PROFESSIONAL PREPARATION

College/University	Major	Degree &Year
Ithaca College	Computer Science	B.A, 2004
UNC Charlotte	I.T. (Computer Science)	PhD, 2010

B. ACADEMIC/PROFESSIONAL APPOINTMENTS

Researcher, UNC Charlotte, Department of Computer Science (May 2010 – Present)
National Visual Analytics Center Intern, Pacific Northwest National Laboratory, (June-August 2009)

C. PUBLICATIONS

Caroline Ziemkiewicz and Robert Kosara. "Implied Dynamics in Information Visualization," Proceedings of Advanced Visual Interfaces, 215-222, 2010, http://viscenter.uncc.edu/~caziemki/documents/ziemkiewicz10_implied-dynamics.pdf.

Caroline Ziemkiewicz and Robert Kosara. "Preconceptions and Individual Differences in Understanding Visual Metaphors," Computer Graphics Forum, 28, 911–918, 2009, http://viscenter.uncc.edu/~caziemki/documents/ziemkiewicz09_preconceptions.pdf.

Remco Chang, **Caroline Ziemkiewicz**, Tera Green, and William Ribarsky. "Defining Insight for Visual Analytics," IEEE Computer Graphics and Applications, 29, 14–17, 2009, http://viscenter.uncc.edu/~caziemki/documents/cga-viewpoints-insight.pdf.

Caroline Ziemkiewicz and Robert Kosara. "The Shaping of Information by Visual Metaphors," IEEE Transactions on Visualization and Computer Graphics, 14, 1269–1276, 2008, http://viscenter.uncc.edu/~caziemki/documents/ziemkiewicz08_visual-metaphors.pdf.

D. SYNERGISTIC ACTIVITIES

I co-founded UNC Charlotte's student chapter of ACM-W (ACM's Women in Computing) as a project for the STARS Alliance, an organization committed to increasing participation by underrepresented groups in the computing field. I have served as a paper reviewer for the IEEE Information Visualization conference, IEEE Visualization, IEEE Visual Analytics Science and Technology, and IEEE PacificVis. I also served as a student volunteer at IEEE VisWeek for one year and at IEEE Virtual Reality for four years.

COLLABORATORS AND OTHER AFFILIATIONS

Graduate and Postdoctoral Advisors
Robert Kosara (UNC Charlotte)

MARK J. SCHNITZER Assistant Professor, Departments of Biological Sciences and Applied Physics, Stanford University; Investigator, Howard Hughes Medical Institute.
Phone: 650-725-7438 Email: mschnitz@stanford.edu

DEGREES

Harvard University, Cambridge MA	Physics	A.B., *summa cum laude*	1992
Cambridge University, Cambridge, UK	Mathematics	Certificate, Part III	1993
Princeton University, Princeton, NJ	Physics	M.A.	1994
Princeton University, Princeton, NJ	Physics	Ph.D.	1999

RESEARCH EXPERTISE: Optical microscopy, biophotonics **YEARS IN THE FIELD:** 10

RECENT PROFESSIONAL POSITIONS

2008-*present* Investigator, Howard Hughes Medical Institute.
2003-*present* Assistant Professor, Dept. of Biological Sciences and Dept. of Applied Physics, Stanford University, Stanford, CA.
1999-2003 Member of Technical Staff, Principal Investigator, Physical Sciences Laboratory, Bell Laboratories, Lucent Technologies, Murray Hill, NJ.

AWARDS AND HONORS

Michael & Kate Bárány Young Investigator Award, Biophysical Society, 2010; NIH Director's Pioneer Award, 2007; Best Methods Paper, American Society of Biomechanics, 2007; Member of The Brilliant 10, Top ten brilliant scientists under age 40, 2007 Popular Science; W.H. Coulter Translational Partner Funding Award, 2006; Terman Fellow, Stanford Univ, 2006; Beckman Translational Research Program Award, 2005; David & Lucille Packard Fellowship in Science & Engineering, 2005; Presidential Early Career Award in Science & Engineering, awarded at White House 6/13/2005; Alfred P. Sloan Research Fellowship, 2005; Klingenstein Fellowship in the Neurosciences, 2004; Young Investigator Award, Beckman Foundation, 2004; Young Investigator Award, Office of Naval Research, Cognitive & Neural Division, 2004; World's Top 100 Innovators under age 35, Technology Review Magazine, 2003; Cutting Edge Basic Research Award (CEBRA), National Institutes of Health, 2003; Young Investigator Award, Human Frontier Science Program, 2002; McKnight Technological Innovations in Neuroscience Award, 2000; Burroughs Wellcome Fellowship, Program in Mathematics and Molecular Biology, 1998-1999; Charlotte Elizabeth Procter Honorific Fellowship, Princeton University, 1997-1998; American Heart Association Predoctoral Fellow, 1996-1998; NSF Predoctoral Fellow, 1993-1996; Winston Churchill Fellowship, 1992-1993; Barry Goldwater Fellowship for Excellence in Science, 1990; United States Physics Team, International Physics Olympiad, 1988.

FIVE RECENT RELEVANT PUBLICATIONS

Mukamel, E.A., Nimmerjahn, A., and Schnitzer, M.J. (2009). "Automated cell sorting for large-scale calcium-imaging studies", **Neuron**, *in press.*

Wilt, B.A., Burns, L.D., Ho, E.T.W., Ghosh, K.K., Mukamel, E.A., and Schnitzer, M.J. (2009). "Advances in Light Microscopy for Neuroscience". **Ann Rev of Neuroscience,** 32:435-506.

Barretto RPJ, Messerschmidt B, Schnitzer MJ. (2009) "*In vivo* fluorescence imaging with high-resolution microlenses". **Nature Methods**. Advance online publication: 14 June 2009.

Flusberg BA, Nimmerjahn A, Cocker ED, Mukamel EA, Barretto RP, Ko TH, Burns LD, Jung JC, Schnitzer MJ. (2008) "High-speed, miniaturized fluorescence microscopy in freely moving mice". **Nature Methods**. 5(11):935-8.

Llewellyn ME, Barretto RPJ, Delp SL & Schnitzer MJ. (2008) Minimally invasive high-speed imaging of sarcomere contractile dynamics in mice and humans. **Nature**. 454: 784-788.

JEFF CHI-TAT LAW
Postdoctoral Fellow, Department of Biology, Stanford University.
Phone: (650) 725-4097; Email: lawj@stanford.edu

DEGREES

B.Eng. 2003 Department of Electrical Engineering, Hong Kong University of Science and Technology, Hong Kong, China

2008 Computational Neuroscience: Vision Course, Cold Spring Harbor Laboratory, New York, USA

Ph.D. 2009 Department of Neuroscience, University of Pennsylvania, Pennsylvania, USA. Ph.D. Advisor: Dr. Joshua Gold

PROFESSIONAL POSITIONS

2010- present Postdoctoral Fellow, Department of Biology, Stanford University, California, USA

TEACHING EXPERIENCE:

2006 Teaching Assistant, Cellular Neurobiology, University of Pennsylvania

AWARDS AND FELLOWSHIPS:

2000-2003 Dean's List

2000-2001 Chiap Hua Cheng's Foundation Scholarship

2000-2001 Hong Kong & Kowloon Electrical Appliances Merchants Association Scholarship

2000-2001 MTR Tertiary Scholarship

2001-2002 MTR Tertiary Scholarship

2002-2003 HKTIIT Scholarship

2010 Saul Winegrad Award for Outstanding Dissertation

INVITED PRESENTATIONS:

2008 The Swartz Initiative in Theoretical Neuroscience at Yale Seminar Series: Mechanisms of learning a visual discrimination task.

PUBLICATIONS

Law, C.T. & Gold, J.I. Neural correlates of perceptual learning in a sensory-motor, but not a sensory, cortical area. Nat Neurosci 11, 505-513 (2008).

Gold, J.I., Law, C.T., Connolly, P., & Bennur, S. The relative influences of priors and sensory evidence on an oculomotor decision variable during perceptual learning. J Neurophysiol 100, 2653-2668 (2008).

Law, C.T., & Gold J.I. A reinforcement learning rule can account for both the associative and perceptual learning on a visual discrimination task. Nat Neurosci 12(5), 655-63 (2009).

Law, C.T., & Gold J.I. Shared mechanisms of perceptual learning and decision making. Topics in Cognitive Science 2009 Aug 10 [Epub ahead of print]

Gold JI, Law CT, Connolly P, Bennur S. Relationships between the threshold and slope of psychometric and neurometric functions during perceptual learning: implications for neuronal pooling. J Neurophysiol. 2010 Jan; 103(1):140-54

Budget Justification

A. Senior Personnel

Dr. David Laidlaw is requesting support for 2 months per year of the project. As the PI, he will be responsible for overall management of the multidisciplinary research. His 20 years of experience with interdisciplinary research and his numerous successful collaborations will help to ensure the success of this project. Relevant experience includes a computer science Ph.D. from Caltech, three years of postdoctoral experience in a developmental neurobiology research laboratory, and 10 years as a faculty member in computer science at Brown.

Dr. Steven Sloman is requesting support for 1 month per year of the project. His role will be as a primary source of cognition modeling knowledge and as a user and tester of the software in his own research. Dr. Sloman has a Ph.D. in cognitive science and has been at Brown is a faculty member for many years. He is an active and recognized expert in the areas he will be supporting in the proposed research.

Dr. David Badre is requesting support for 1 month per year of the project. His research involves studying connections within the brain, and he will be one of our early and ongoing test users. Together with Dr. Schnitzer from Stanford, he motivated the project through contacting Dr. Laidlaw's research group to explore how best to interpret diffusion MRI in the context of studying communication between brain areas.

Professor Fritz Drury, Rhode Island School of Design Professor and former Chair of Department of Illustration will provide consulting advice on visual and interaction design. He and Dr. Laidlaw have taught a class on Virtual-Reality Design for Science several times as well as working together on a number of visualization research projects. This established collaboration has helped the scientific visualization research of Dr. Laidlaw's group on a number of projects. Professor Drury is funded as a consultant (see Section F. Other Direct Costs).

B. Other Personnel

Postdoctoral Fellow: Dr. Laidlaw is requesting full time support for Postdoctoral Fellow Caroline Ziemkiewicz for each year of the project. Her cognitive modeling experience in the context of computer science will make her an ideal assistant on this project. She will assist Dr. Laidlaw in day-to-day management of the project, in particular coordinating among the groups and sites.

Bradley Berg, Senior Software Engineer. Dr. Laidlaw is requesting 50% time support for Mr. Berg. Mr. Berg is an expert software engineer, and has been providing support to a number of Dr. Laidlaw's projects for the last 18 months. He has helped to develop a source control and build system for Dr. Laidlaw's research group, and has deployed an upcoming virtual-reality library to Source Forge, an open source software repository. Mr. Berg will also be responsible for creating and running regular tests to ensure that the software is reliable, and for providing installation and infrastructure support for external users. He will also ensure that the software works across platforms and across operating system versions.

Graduate Students: support is requested for five to-be-named graduate students for each year of the project. Three graduate students will work 100% time in Computer Science with Dr. Laidlaw. Two graduate students will work in Cognitive & Linguistic Sciences; one will work 100% for Dr. Sloman and the second 50% for Dr. Badre. The graduate students in computer science will develop the primary software as well as run user experiments to test the efficacy, functionality, and usability of the software. They will also implement the cognition modeling algorithms and evaluate their applicability. One will be primarily responsible for Cave-related experimentation and evaluation. The graduate students in cognitive and linguistic sciences will help to provide input on cognitive modeling, together with their faculty advisors, and will supervise and run cognitive tests helping to evaluate the underlying cognitive models. They will also use the software themselves to support their research and to provide feedback on its efficacy. Please note salary support is for stipend only; graduate tuition is included in budget section G.6. Other Direct Costs - Other.

Undergraduate Students: support is requested for three full-time undergraduate students, each to work twelve months each year. One will work in Computer Science with Dr. Laidlaw; the other two will work in Cognitive & Linguistic Sciences (one with Dr. Sloman and one with Dr. Badre). The undergraduate working with Dr. Laidlaw will be responsible for assisting Ph.D. students in developing software. Dr. Laidlaw's lab has a history of including undergraduates in research like this, and many of them have been drawn into the field and gone on to top Ph.D. programs and research careers. The undergraduates working with Dr. Sloman and Dr. Badre will primarily help to run user studies.

C. Fringe Benefits

Fringe Benefits are budgeted at Brown's approved rates which are 31.7% for faculty, post-doctoral, and staff salaries, and 8.3% for student summer salaries

D. Equipment

Equipment: funding is requested to acquire a pupil tracking device. Pupil tracking is one of the most accurate indicators of human attention, and tracking it will help to evaluate our cognitive models.

E. Travel

Proposed funding is requested for visiting research collaborators at Stanford and for attending scientific conferences.

F. Other Direct Costs

Materials and Supplies: $2,500 is requested in the first year for a computer to run experiments.

Consultant Services: Professor Fritz Drury (see additional description in Section A. Senior Personnel).

Computing costs: Brown's Computer Science Department supports the computational needs of this research via the Computing line item on the budget. The department's technical staff acquires and supports high-end graphics workstations for each student, the PI, and within shared lab space. Support includes software installation and maintenance, network access, file backup and restoration, and printing. The amount proposed for each year is calculated at 6.74% of costs projected for the project excluding graduate tuition.

Other: Included on the G.6. Other Direct Costs - Other line is $2,000 each year for experimental participant pay plus Graduate Tuition and Health Fee. These are in the following amounts: $59,390 Year 1; $62,308 Year 2; $65,371 Year 3; $68,584 Year 4; $71,956 Year 5.

G. Indirect Costs

Brown's approved indirect cost rate is used here: 62% MTDC. This rate was approved for Brown University by the U.S. Department of Health and Human Services on January 25, 2010.

SUMMARY PROPOSAL BUDGET COMMENTS - Year 1

**** I- Indirect Costs**
Facilities and Administration (Rate: 58.0000, Base 187648)

Budget Justification

A. Senior Personnel

Prof. Mark J. Schnitzer, PI, 1% (0.12 calendar months) effort

Prof. Mark Schnitzer of Stanford's Departments of Biology and of Applied Physics is a recognized expert in the innovation and application of optical techniques for *in vivo* brain imaging. He has invented two forms of fluorescence microendoscopy for imaging cells lying deep within tissue beyond the optical penetration depth of conventional light microscopy. Based on his initial work, microendoscopy is currently being applied in basic neuroscience research and for minimally invasive imaging in human patients. Schnitzer's core interests now center on using microendoscopy to study neural circuits deep within the living brains of live mice. Prof. Schnitzer will oversee and set priorities for all experimental work and will be responsible for all data interpretation and analysis. He will also be responsible for disseminating our results in a clear and timely fashion through publications and meeting presentations. No funds are requested for salary, which is covered entirely by Prof. Schnitzer's employment as an HHMI Investigator.

Jeff Chi-Tat Law*, Postdoctoral Fellow, 50% effort (6 calendar months)*

Dr. Schnitzer is requesting 50% support for postdoc Jeff Chi-Tat Law. Dr. Law has extensive expertise in neural circuits involved in forming perceptual decisions, the underlying computations and how these computations are shaped by experience. His Ph.D. research in the laboratory of Prof. Gold at the University of Pennsylvania focused on perceptual learning in sensory-motor areas of monkeys. He also is a graduate of the Computational Neuroscience: Vision Course at Cold Spring Harbor Laboratory. As a postdoctoral fellow, Dr. Law is applying his expertise to study modulation of sensory processing using imaging technology created in the Schnitzer lab. Dr. Law's research will benefit greatly from the use of tools created in this grant.

C. Fringe Benefits

This budget was constructed for the period 1/01/2012 to 12/31/16. According Stanford University guidelines, a cost-of-living increase of 3% was assumed for salaries and a 3% inflation rate was assumed for all other categories except where noted. These increases have been projected into all years of the budget. The fringe benefit rates are as per our final negotiated rate agreement with the Office of Naval Research (ONR) on 08/09/2010.

D. Travel

Proposed funding is for attending the annual meeting, visiting research collaborators at Stanford and the collaborating institutes, and for attending scientific conferences.

E. Other Direct Costs

Materials and Supplies: $4,000 is requested for each year to cover the costs of wet lab, histological, animal, and optical supplies needed to test the utility and validate the brain visualization approach being created in this grant.

Animals: $3000 is requested for each year to cover costs of animal (mouse) care. Animal per diem charges at Stanford University reflect the implementation of OMB Circular A-21 and represents full recovery of direct costs of specialized service facilities. The proposed agreement on indirect costs between the Office of Naval Research and Stanford University specifies that animal care charges and services carry a separate indirect cost rate which is excluded from, and does not duplicate, Stanford University's Modified Total Direct Cost (MTDC).

F. Indirect Costs

Stanford University's provisional Facilities & Administrative Costs rate negotiated on 8/23/2010 with ONR is 58%, which is charged to the modified total direct costs base.

MENTORING PLAN FOR POSTDOCTORAL RESEARCHER JEFF LAW

Postdoc Dr. Jeff Law will be involved in the proposed research at a level of 50% effort. Jeff has ~0.5 years of postdoctoral experience in the Stanford group; the mentoring he will receive will be tailored to that of an talented postdoc preparing to enter the US academic job market in the next 2-3 years. Here we describe the mentoring program we have followed to date and will continue to follow towards fostering Jeff's scientific development:

Interdisciplinary Collaboration. Jeff is involved in collaborations with researchers and now laboratories outside his areas of expertise. Overall, our lab's work is heavily interdisciplinary, and so at lab meetings Jeff has key opportunities to present his work to a diverse audience and receive feedback from Professor Schnitzer.

Training in Grant Preparation. Prof. Schnitzer likes to involve each postdoc in the lab in the writing of a grant. This is a good way to convey basic skills in grantsmanship. To support the 50% of Jeff's effort not covered by the present proposal, we plan to write another grant and Jeff will be a major participant in the preparation.

Guidance on Improving Mentoring and Presentation Skills. As a Ph.D. student, Jeff has had opportunities to work closely with junior graduate students. Now as a postdoc, Jeff will be able to participate in the mentoring of one graduate student in the Schnitzer lab. Jeff is also encouraged to gain formal teaching opportunities here at Stanford. As Jeff's postdoctoral work progresses, he will also be encouraged to make presentations at suitable scientific conferences. Additionally, on occasions when Prof. Schnitzer must decline a symposium invitation, he generally sends a postdoc representative from the lab. Jeff is very likely to receive such opportunities for giving major talks, in addition to more standard slide format conference presentations.

Career Counseling and Guidance. Stanford has a regular series of seminars for educating postdocs regarding how to become a Principal Investigator and how to run a scientific laboratory, manage personnel, and write grants, as well as issues in scientific ethics. We encourage Jeff to attend all of these seminars and he does so regularly. In addition to the regular seminars that include ethics, Prof. Schnitzer has occasional discussions with lab members about ethical thinking driven by scientists' core values. This pertains to commonplace issues of authorship, data interpretation, mentoring, control experiments, professional responsibilities, etc. Jeff also has regular meetings with Professor Schnitzer to review both progress on research and towards career goals. Knowing that Jeff is interested in academe, e.g. rather than industry, helps enormously in guiding his steps and providing career advice.

MENTORING PLAN FOR POSTDOCTORAL RESEARCHER CAROLINE ZIEMKIEWICZ

Dr. Caroline Ziemkiewicz will also be involved in the proposed research as part of the Brown group for an expected appointment of two years. Our mentoring plan is designed to aid Dr. Ziemkiewicz in her development of her own long-term research and professional goals and transition her into an independent researcher.

Interdisciplinary Collaboration. Caroline will work closely with students and faculty in our group to pursue a research agenda that branches human-computer interaction, computer science, and cognitive modeling. This research will include regular collaboration with cognitive scientists and scientific domain experts.

Publication and Training in Grant Preparation. Caroline will receive assistance in the process of writing and publishing these results in reputable journals and conferences. She will be involved in preparing further proposals, as a Co-PI or a PI, to garner funding to support work on the project, and we will jointly determine how to appropriately share any resulting awards after her departure.

Career Counseling and Guidance. Dr. Laidlaw will be available to meet with Caroline weekly throughout the period of the mentorship, focusing on her evolving career and research goals. Initially, we will work to define these goals; subsequently we will evaluate whether she is on an appropriate trajectory to reach them. This teleological approach to mentoring naturally supports technical advising on the research itself while preserving the higher-level goals of both the mentee and mentor.

Guidance on Improving Teaching and Presentation Skills. Caroline will participate in the teaching of several relevant classes taught by Dr. Laidlaw, including a course titled "Virtual Reality Design for Science," which is offered jointly with the Rhode Island School of Design and will provide a unique opportunity to learn how to teach in an interdisciplinary environment. She will also lead group discussions in research meetings and will have the opportunity to teach her own computer science course at Brown.

PARTNER INSTITUTIONS

Academic Institutions:
Brown University
Stanford University

National Laboratories:
none

Federal Government:
none

Industry:
none

Non-Governmental Organizations:
none

State and Local Governments:
none

International:
none

Other:
none

PROJECT SENIOR PERSONNEL

Laidlaw, David, Brown University
Badre, David, Brown University
Sloman, Steven, Brown University
Drury, Fritz, Rhode Island School of Design
Ziemkiewicz, Caroline, Brown University
Schnitzer, Mark, Stanford University
Law, Jeff, Stanford University

PROJECTED COMMITMENTS

No institutional commitments have been made.

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
Chief Critic, RISD European Honors Program, Winter & Spring 2011.
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, with Joanne Stryker, 2008 Prentice Hall, Upper Saddle River NJ.

Visualization Criticism in *IEEE Computer Graphics and Applications*, 28(3):13-15,
2008, with Robert Kosara, Lars E. Holmquist, and David H. Laidlaw.

Using Visual Design Expertise to Characterize the Effectiveness of 2D Scientific Visualization Methods in *Proceedings IEEE Visualization, Poster Compendium (BEST POSTER AWARD) October 2005*, with Daniel Acevedo, Cullen Jackson & David Laidlaw.

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

September-December 2002, 2004, 2006 & 2008 – 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.

November 2008 – advisor to Colin Ware, author of *Visual Thinking for Design* (2008), on visualization strategy.

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; Sharon Swartz, Ecology and Evolutionary Biology, Brown University; Joanne Stryker, Rhode Island School of Design; 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, Daniel Acevedo, Cullen Jackson & Jadrian Miles, 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

Results of Prior Support

a David H. Laidlaw

Over the last five years David Laidlaw's research group has been funded by several NIH awards or subcontracts to NIH awards, continuation funding from several NSF awards and a Keck Foundation grant, and one recent NSF instrumentation grant. Most of the NIH awards and subcontracts related to developing and applying computational tools for the analysis of diffusion MRI imaging data. Laidlaw's group has published extensively in this area with collaborators from around the world. Another NIH award was for developing computational bioengineering tools to study the human carpus in collaboration with PI Joseph Crisco in the Department of orthopedics. A final NIH subcontract involves creating interactive tools for studying gene expression in the immune system. This is in collaboration with Christophe Benoist at Harvard Medical School. Laidlaw's most recent NSF funding was an MRI award to develop a new virtual reality display instrument at Brown. That project is in year two of four. Finally, he has been a co-PI on Keck and NSF awards to study animal kinematics and dynamics. In the last five years his research has led to about 25 refereed journal articles, approximately 10 refereed conference papers, two patent applications, and about 40 conference abstracts or posters. Laidlaw has been recognized via a number of best poster and best panel awards at conferences and received in 2008 the prestigious IEEE VGTC Visualization Technical Achievement Award.

b Steven Sloman

Steven Sloman's primary sources of funding over the past 5 years have been an NSF award entitled "Causal Models of Decision Making: Choice as Intervention" and a research contract with Unilever Corporation entitled Designing Products to Cue Causal Reasoning. The latter project is too recent to have generated reportable results. The NSF project was designed to test the hypothesis that decision makers are actively trying to understand their environments in order to construct and use causal models that predict the effects of their choices on themselves, on others, and on the world around them. The project has yielded results of 4 types: (i) It has shown that people are highly sensitive to causal structure when making judgments (Fernbach, Darlow, & Sloman, 2010a, 2010b), decisions (Park & Sloman, 2009; Walsh & Sloman, 2008) and that they treat choice as an intervention, not an observation (Hagmayer & Sloman, 2009; Sloman & Hagmayer, 2006). Intervention is a formal notion in a graphical probability model that represents a change in state as a result of an exogenous variable that is sufficient to determine the value of a choice variable. It is usually assumed to be the product of an intentional action by a willful agent. (ii) We have found support for a model of decision making that frames decisions in terms of causal expected utility in contrast to a more standard frame of evidential expected utility. Support comes from studies that examine both simple choices (Hagmayer & Sloman, 2009) and two-player games (Robinson, Sloman, Hagmayer, & Hertzog, in press). (iii) We have examined various actual and apparent boundary conditions on the theory such as the role of self-deception in choice. People will choose a self-serving frame when the situation allows them to hide their actions from themselves (Sloman, Fernbach, & Hagmayer, in press). (iv) We have used the causal model framework to develop computational models of specific functions, including the interpretation of causal verbs (Sloman, Barbey, & Hotaling, 2009) and how people judge the intentionality of someone else's action (Sloman, Fernbach, & Ewing, 2010).In 2009, Sloman was the Robert J. Glushko Distinguished Visiting Scholar in Cognitive Science, University of California, Berkeley. This award supported a lecture series and workshop in Berkeley in which Sloman reviewed the state of knowledge of human causal reasoning, judgment, and decision making.

c David Badre

Research in David Badre's lab since his hire at Brown in 2008 investigates the neural systems that support memory and cognitive control. They have made a number of contributions to the understanding of the neural mechanisms of cognitive control and memory, and most notably with regard to frontal lobe organization and function. One funded line of work (NIH R01 NS065046) has begun to test the hypothesis that the frontal lobes are organized in a processing hierarchy along the rostro-caudal axis that translates abstract goals and plans into concrete actions (for reviews see Badre, TICS, 2008; Badre et al., Nature Reviews Neuroscience, 2009). In an initial experiment, they demonstrated that as rules by which responses are selected become more abstract in terms of the number of contingencies they entail, progressively rostral portions of frontal cortex

were selectively activated in fMRI (Badre et al., JOCN, 2007). They then demonstrated that damage to focal regions of frontal cortex impaired control at a level of abstraction determined by its rostro-caudal locus as predicted by fMRI (Badre et al., Nature Neuroscience, 2009). Moreover, all tasks that required more abstract control were also impaired, while those requiring only less abstract control were left intact. This pattern of deficits provided the first direct evidence that interactions among frontal regions are asymmetric such that rostral frontal regions influence processing in caudal regions more than vice versa. Such asymmetry is characteristic of a hierarchical architecture. In more recent work, they have demonstrated that hierarchical structure is important for generalizing behavioral rules during a reinforcement learning task (Badre et al., Neuron, 2010). Based on these data, they have developed a computational model that can simulate learning in this task and that makes specific predictions about the dynamics between striatum and frontal cortex that could support hierarchical control (Frank and Badre, submitted). A key feature of the model is the proposal that hierarchical control emerges from interactions among a series of nested cortico-striatal loops arrayed rostro-caudally in frontal cortex. They continue to actively pursue this line of work within the lab's broader research program, including expanding its scope to test how genotypic variation and disorders like autism may affect processing dynamics within this functional architecture and how such a functional architecture might emerge during development.

d Mark Schnitzer

Schnitzer had an NSF grant (Award 0352456) from 2004-2007 that involved the development of fiber-optic microscopy for use in freely moving rodents. This work led to 5 patent filings and 10 publications – including more papers to date on Ca2+ imaging in awake behaving animals than from any other lab – and sparked the ideas proposed here. For this body of NSF-supported papers, Schnitzer was recently named the 2010 recipient of the Michael and Kate Barany Young Investigator Award from the Biophysical Society.