Interactive Display and Analysis of Local and Global Changes In Carpal Bones Throughout a Full Range of Kinematic Motion in the Human Wrist

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Collaborator: Dr. Joseph (Trey) Crisco[3]

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Abstract:

We propose an interdisciplinary project that proposes a solution to the visualization problem of viewing details within a global context while investigating carpal bone motion in the human wrist in an effort to gain insight into joint movement and derive metrics for classifying various pathologies.

A. Specific Aims:

We will develop a tool that is able to allow for a researcher or clinical physician to track the local changes that occur in the various carpal bones in the human wrist as a function of global wrist position. Different metrics that describe bone position as a function of global wrist position will be calculated and used to derive certain visualizations. By incorporating visualizations of set contour levels and points on a bone surface at which the minimum distance occurs as functions of kinematic wrist motion, one of the top visualization problems of being able to view details within the larger context of large scale flexion versus extension and radial versus ulnar deviations will be solved [1]. Furthermore, the use of a tool that is able to accurately describe position, and how that position relates to other bones at the single carpal bone level, has the ability to serve as a diagnostic tool for various wrist pathologies. It is our hypothesis that this tool will allow wrist pathologies to be quantified and tracked for different populations at a more in-depth level, at the bone surface level, than is currently allowed by medical imaging techniques and impossible to do with the use of the presently available visualization software.

B. Background and Significance:

We are proposing a novel way to visualize carpal bone movements in the human wrist at the local, single bone level, while, at the same time, the global movement of the kinematic position of the wrist can also be seen and tracked. This proposed visualization has the ability to provide great insight into the complex translational and rotational movement of all individual carpal bones while there is a large scale movement of the whole wrist. From the computer science prospective, this work is novel in that it attempts to solve the visualization problem of visualizing details within a larger context. Furthermore, this tool has the potential to also positively impact the fields in orthopedics and medicine by allowing clinicians and researchers to examine pathological conditions such as fractures and arthritis in a more magnified manner.

B.1. Background: The Pathologies of the Human Wrist

The human wrist is a complicated collection of bones, the carpals, that routinely undergo irregular translations and rotations during movement. These irregularly shaped carpal bones are aligned in two rows of four bones each (**Figure 1**) . Because the 80% of the surface area of the carpal bones is covered with articular cartilage, the wrist is prone to degenerative osteoarthritis as age increases [2]. Furthermore, the carpals are also prone to fractures from traumatic events, or even due to movements in active individuals [3]. Due to the fact that the carpals are constantly and inconsistently undergoing movement, they are subject to various injuries.

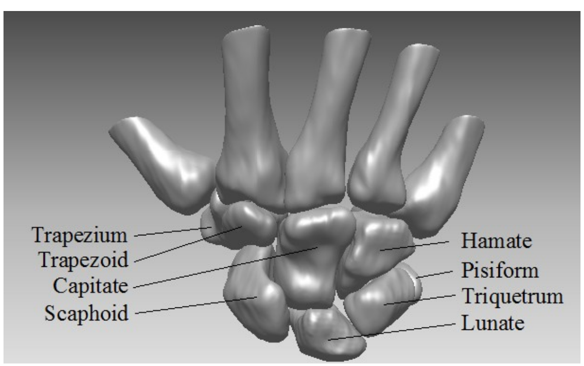

Figure 1*: The anatomy of the human wrist in a clinically neutral anatomical position.*

Currently physicians use computed tomography (CT) and magnetic resonance imaging (MRI) to examine these pathologies, but they merely examine the entire set of carpal bones and do not examine the kinematics or individual bone surfaces to diagnose and treat their patients [4,5]. By implementing a visualization of a local view of the carpal bones and their associated kinematics, we believe that we will be able to better diagnose and monitor treatment efficacy in pathologically positive patients as well as gain valuable understanding of the movement of the carpal bones at the level of individual carpal bones.

B.2. Background: Existing Global View Software Platform

In 1989, the Visible Human Project was established by the National Laboratory of Medicine, and its foundation established a new paradigm for the use of medical images in biomedical and clinical research [6,7]. These images, however, were simply static, and usually proved difficult to relate to kinematic data in an effort to understand movement in the musculoskeletal system [8]. With the introduction of more accurate CT acquisition methods of bone surfaces, it has become possible to directly relate *in vivo* kinematics [9]. Recently, our group has released a publicly available digital database of carpal bone anatomy and kinematics. As a part of this database, a simple viewer is available that is able to show the carpal bones and their kinematic movements [8].

The current functionality of the viewer associated with the public data base is limited to simply being able to display bone surfaces with the ability to cycle through kinematic positions. It is our belief that adding functionality to this viewer with different metrics that are a function of kinematic position at the inter-joint space level will greatly improve the potential of this visualization tool as a way to test different hypothesis, and allow it to serve as a diagnostic tool for clinicians. Furthermore, it will allow them to examine carpal bones at both the global and local levels, which has never been done, and has proven to be an impeding, pervasive visualization problem that has plagued medical imaging community.

C. Preliminary Work:

We have developed two specific methods that can be used to better quantify and describe carpal movement at the local level. Both of the methods incorporate the concept of minimum distance measurements between contacting carpal bones. The first method provides a way to track how the point of articulation changes as a function of kinematic position. By utilizing the aforementioned digital database of carpal bone anatomy and kinematics, the minimum distance between pairs of adjacent carpal bone was calculated and the locations at which it occurs was mapped onto the surfaces of each bone (**Figure 2**). We have been able to qualitatively show that the point of minimum distance does change as a function of kinematic motion by examining the bone surface in the context of global wrist motion.

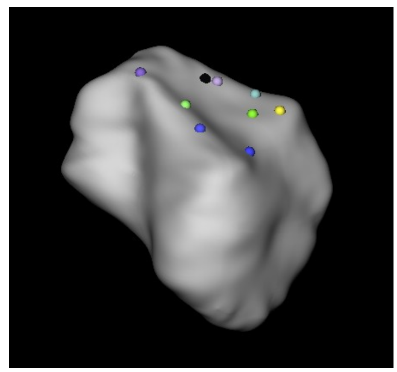

***Figure 2**: Marked positions of inter-bone minimum distance on a trapezoid measured to the scaphoid as a function of kinematic position.*

The second method utilized a visualization of a fixed-distanced contour of the three-dimensional bone surface and how it changes over the range of kinematic motion. Previous work has been able to show that contact area and inter-bone distance in the distal radioulnar joint (DRUJ) does change as a function of pronation and supination [10]. Building from that, and adding a larger kinematic range of motion that includes flexion, extension, radial deviation, and ulnar deviation, we have been able to show that the level set contours between the bones change under the full range of motion (**Figure 3**).

To this point, all of the work that has been done is crucial because it allows for more detailed analysis of bone movement in the human wrist than has previously been done, and it further demonstrates that the inclusion of a local view to the global movements of the wrist are important in understanding the full dynamics of joint movement.

D. Methods:

Functionality will be added to an already existing wrist bone kinematics viewer that has been previously been developed by our group. Also, the newly added features will be used to compare carpal bone movements for different subject relative to each other, and among populations that have demonstrated clinical pathologies in an effort to advance the clinical understanding of the human wrist.

D.1. Adding Functionality to the Existing Software Package:

The metrics that describe the locations of the minimum inter-bone distances and the level-set contouring will be added to the existing graphical user interface (GUI) wrist bone viewer. The increase of function is derived from the inclusion of toggles that will allow for binary user adjustments of the local visualizations. The newly added local views will be able to be viewed with the global set of all carpal bones throughout the full kinematic range of motion of the human wrist.

D.2. Examination of Local Changes as a Function of Global Wrist Movement:

Once all of the new functionality is added to the GUI, it will be possible to evaluate the collection of subjects in the public digital database of carpal anatomy and kinematics. By examining a large population of healthy subjects, trends in carpal bone movement can be found, and then further compared to subject populations that have positive pathologies. These trends will be found by utilizing statistical tests that show significant changes in position of inter-bone minimum distance and changes in contour area. A t-test will be used to measure the significance in change in position in three-space of a point of minimum distance on a bone surface as well as the change in area as of the fixed-distance contouring as function of kinematic wrist motions.

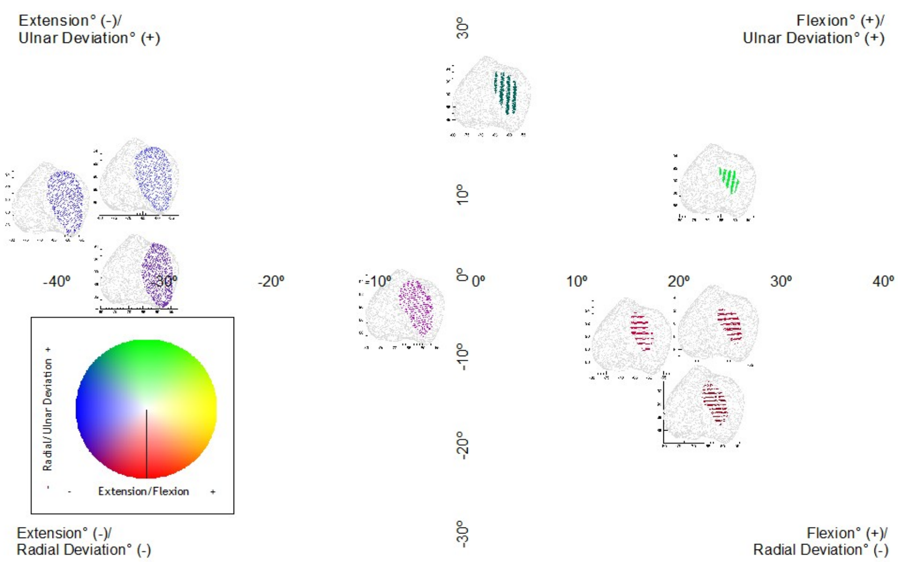

***Figure 3**: The changes of a fixed-distance contour on a scaphoid on a typical scaphoid-trapezium joint.*

E. Verification:

By using a publicly available database as the source for all data in this project, it is our belief that all methods used to calculated the discussed metrics can be repeated by anyone wishing to do so. Thus, this is a naturally implemented check to insure that proper algorithms and calculations are truly being used in an effort to characterize wrist bone movement on the local level.

F. Timeline:

Week 1: Gain familiarity with the source code of the currently used carpal bone viewer.

Week 2: Implement the methods to be able to visualize the point at which minimum distances occur as the kinematic position changes. Add features to be able to control the display parameters of this visualization to the GUI.

Week 3: Add the set-level contouring feature to the GUI. Add the ability to control this local visualization to the GUI.

Week 4: Create a split-screen that is able to show both the local and global views of the carpal bones as their kinematic position is changed. Implement error checking, debug, and test the added visualizations with the subjects in the database.

Week 5: Compute statistics for all subjects in the database. Begin to compute statistics for pathological subjects.

Week 6: Finish computation of statistics for abnormal subjects. Prepare final report and final presentation of this project.

G. References:

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5. RR Pillai, B Thoomukuntla, GA Ateshian and KJ Fischer. MRI-based modeling for evaluation of in vivo contact mechanics in the human wrist during active light grasp. J*ournal of Biomechanics,* 40(12):2781-2787, 2007

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10. GE Marai, DH Laidlaw, C Demiralp, S Andrews, CM Grimm, and JJ Crisco. Estimating Joint Contact Areas and Ligament Lengths From Bone Kinematics and Surfaces. *IEEE Transactions on Biomedical Engineering,* 51(5):790-798, May 2004

H. Participant List and Associated Qualifications and Capabilities:

Andrew J. Wald

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EDUCATION

Brown University
Providence, Rhode Island USA
Ph.D. Student in Biomedical Engineering
September, 2005-Present

Vanderbilt University
Nashville, Tennessee USA
Bachelor of Engineering in Biomedical Engineering
August, 2001- May, 2005

RESEARCH INTERESTS

Utilization of computational and visualization tools for medical imaging applications, including computed tomography (CT) and magnetic resonance imaging (MRI).

RESEARCH EXPERIENCE

Scientific Visualization Group – Brown University (Dr. David Laidlaw)
- Developing metrics to characterize wrist kinematics and study the effects of motion within both healthy and pathological populations. (January, 2007 - Present)

High Resolution Functional MRI Laboratory – Brown University (Dr. David Ress)
- Modeled cerebral blood flow at the capillary level through the use of high resolution functional magnetic resonance imaging and mathematical models that included electrical circuit component equivalents. (August, 2005 – December, 2006)

Vanderbilt University Institute of Imaging Science – Vanderbilt University (Dr. John Gore and Dr. Thomas Yankeelov)
- Utilized dynamically contrast enhanced (DCE) MRI to track treatment efficacy of breast cancer. Developed a general graphical user interface for MRI viewing for non-technical uses.

PROFESSIONAL EXPERIENCE

Teaching Assistant – Brown University Department of Biology and Medicine. Organ Replacement (Spring, 2007) and Genetics (Fall, 2006)

Product Applications Engineer - Research Systems Incorporated (Boulder, Colorado). Developed applications and demonstrations for automated analysis of CT and MRI images (Summer 2005)

Trevor M. O'Brien

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EDUCATION

College of the Holy Cross
Worcester, Massachusetts, USA
Bachelor of Arts in Mathematics and Computer Science *(magna cum laude)*

RESEARCH *INTERESTS*

Medical imaging, physically-based rendering, real-time graphics.

EXPERIENCE

Computer Science Researcher at Brown University (Summer, 2006 – Present)
- Developing a software package that will allow scientists to view and interact with high resolution videos of 3D skeletal models. Responsible for implementing, testing, and optimizing various software tools used to capture and analyze motion data. Research funded by the Keck Foundation.

Instructor of Mathematics at Groton School, Groton, MA (June 2006 - June 2007)
- Taught AP Calculus, Geometry, and Algebra 2, Trigonometry, as well as an introductory programming course. Served as assistant coach to the varsity basketball and baseball teams.

Software Engineer at Mad Doc Software, LLC. Andover, MA (June 2005 - June 2006)
- Responsible for creating and maintaining several game systems for the PC and Microsoft XBox 360 title *Star Trek Legacy* published by Bethesda Softworks. Developed various modes of online play, maintaining network-safe code. Aided in the communication between designers and developers, regularly presenting new ideas and algorithms to the production team.

COMPUTER SKILLS

Languages: *Proficient in: C/C++, Java, XML, HTML, Javascript,* and Familiar with Perl, Lua, PowerPC Assembly.
Software: Microsoft Visual Studio .NET, CodeWarrior, Perforce, Subversion, CVS, Matlab, Microsoft Office.
APIs: OpenGL, DirectX 9/9.5, SDL, G3D, VRG3D

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Education:
Ph.D., Engineering and Applied Science, Yale University, New Haven, Connecticut.
B.A., Mathematics and Fine Art, Amherst College, Amherst, Massachusetts

Biomechanics of musculoskeletal joints and injury prevention:

Our most recent work is focused on the in vivo study of the normal, pathological, and healing musculoskeletal joint. Measurement of biomechanical variables such as 3D kinematics, ligament strain, and joint contact are performed with our novel in vivo methods using sequential CT scans. Earlier studies on ligament impact biomechanics and muscle contusion injuries examined the basic science of injuries. Applied work on injuries has lead to the development of a telemetry system for measuring head acceleration in athletes and to a study of the performance differences between wood and aluminum baseball bats. Current studies are aimed at in vivo cartilage strains, mechanotransduction of chondrocytes, and the multi-directional biomechanics of the spine.

I also consult on injury prevention and protective sports equipment to manufacturers and various governing bodies including the NCAA, NHFS, National Operating Committee on Standards for Athletic Equipment (NOCSAE), USA Baseball, US Lacrosse, and the International Federation of Women's Lacrosse Association.

Recent Publications (of 109):

Crisco JJ, Pike S, Hulsizer-Galvin DL, Akelman E, Weiss A-PC, Wolfe SW; Carpal bone postures and motions are abnormal in both wrists of patients with unilateral scapholunate interosseous ligament tears. J. Hand Surgery, 28(6): 926-937, 2003

Sonenblum SE, Crisco JJ, Kang L, Akelman E, In vivo motion of the scaphotrapezio-trapezoidal (STT) joint. J. Biomechanics, 37(5): 645-652, May 2004.

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Crisco JJ, Coburn JC, Moore DC, Upal MA. Carpal Bone Size and Scaling in Men and Women. Journal of hand Surgery, 30(1):35-4, 2005 Jan.

Duma SM, Maoogian SJ, Bussone WR, Brolinson PG, Goforth MW, Donnenwerth JJ, Greenwald RM, Crisco JJ. Analysis of Real Time Head Accelerations in Collegiate Football Players. Clinical Journal of Sports Medicine, 15(1):3-8, 2005 Jan.

Coburn J, Crisco JJ, Interpolating Three-Dimensional Kinematic Data Using Quaternion Splines and Hermite Curves, Journal of Biomechanical 91. Wolfe SW, Orr C, Marzke M, Crisco JJ, Clinical and Anthropological significance of the Dart-thrower's motion of the wrist, The Journal of Hand Surgery, accepted August 2006.Engineering, 127(2):311-317, April 2005.

Spenciner D, Palumbo M, Green D, Paiva J, Crisco JJ. The Multi-Directional Bending Properties of the Human Lumbar Intervertebral Disc. The Spine Journal. Accepted August, 2005

Crisco JJ, Coburn JJ, Drewniak LI, Spenciner DB, Physical and Mechanical Properties of Various Field Lacrosse Balls, Journal of Applied Biomechanics, 21:383-393, November, 2005.

Crisco JJ, Coburn JJ, Moore DC, Akleman E, Weiss A-PC, Wolfe SW, In Vivo Radiocarpal Kinematics and the Dart Thrower’s Motion, Journal of Bone and Joint Surgery, 87(12):2729-40, 2005.

Marai GE, Laidlaw DH, Crisco JJ, Super-Resolution Registration Using Tissue-Classified Distance Fields. IEEE Transactions on Medical Imaging, 25(2):177-87. 2006.

Coburn, JC, Upal, MA, Crisco JJ, Coordinate Systems for the Carpal Bones of the Wrist, Journal of Biomechanics, 2006 (in press).

Alford JW, Bradley MP, Moore DC, Crisco JJ, Fadale PD, Ehrlich MG, Resorbable Fillers Reduce Stress Risers from Screw Holes, J Trauma 2006 (in press)

Spenciner DB, Greene D, Paiva J, Palumbo M, Crisco JJ, The multidirectional bending properties of the human lumbar intervertebral disc. Spine J, 2006 May- June; 6(3):248-257.

Andermahr J, Lozano-Calderon S, Trafton TT, Crisco JJ, Ring D, The Volar Extension of the Lunate Facet of the Distal Radius: A Quantitative Anatomic Study, Journal of Hand Surgery, 2006 (in press).

Yang X, Vezeridis P, Nicholas B, Crisco JJ, Moore DC, Chen Q, Differential Expression of Type X Collagen in a Mechanically Active 3-D Chondrocyte Culture System: a Quantitative Study, J Orthopaedic Surgery and Research, accepted June 2006

Society Memberships:

American Society of Biomechanics (ASB)

American Society of Mechanical Engineers (ASME)

Cervical Spine Research Society (CSRS)

International Society of Biomechanics (ISB)

Orthopaedic Research Society (ORS)

International Society for Skiing Safety (ISSS)

I. Letter of Support:

Dear Andy,

I am looking forward to being a collaborator with you on your class project. Adding features that allow a more interactive viewing of inter-bone distance metrics, ligament elongation, and cartilage deformation into the already existing wrist kinematic view has great potential to further orthopedic research at Brown University. I am happy to provide any guidance or answer any questions that may arise.

Sincerely,
Trey Crisco

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**Sent via electronic mail (10/2/07)*

Interactive Visualization of Spaceborne Body Collision Simulations

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Consultants: Peter Schultz[2], Brendan Hermalyn[2]

[1]Brown University, Department of Computer Science

[2]Brown University, Department of Geological Sciences

Abstract:

We propose an interdisciplinary research project to develop a novel interactive tool for visualizing the geometry of solid body particle ejections. Through the use of established mathematical models describing the impact event, our tool which allow the user to visualize their models in a detailed 3-dimensional environment as well as enable the user to interactively manipulate dimensions of their model and visualize the effects

A Specific Aims

We will develop a tool which will color-code particle ejection streams created from impacts based on various particle pre-defined characteristics such as time of ejection, angle of ejection, particle ejecta direction and speed, and particle initial position on impacted body surface [2]. Based on these parameters, we will construct an interface which allows the user to manipulate the dimensions of the particle ejecta as well as the impact and simulate the effects for comparisons with actual video clips as well as simulated lab experiments. Moreover, we hope from observations made and patterns extracted from these simulations, we will be able to develop a framework for classifying sections of particle ejecta into distinct phases, which will not only provide users with an effective visualization tool for understanding particle ejection geometry but also provide some insight into the physics behind disparate stages of the impact.

B Background:

Comets are perceived as keys to the past as they are believed to contain clues about the formation and evolution of our solar system. Composed of ice, dust, gas, and primitive debris, they are generally made up of materials originating from the outermost and frigid domains of solar system and produced nearly four and half billion years ago [1]. On July 4, 2005, NASA launched the Deep Impact mission, which was the first attempt by any organization to collect information about a comet by thrusting an object at it and then analyzing the particle ejections and crater formation resulting from the impact. The spacecraft consisted of two parts, crucial to the overall aims of the mission: a three hundred and seventy kilogram pod-shaped copper-core, dubbed the "Smart Impactor", which was thrust at the comet at approximately 23,000 mph and a flyby probe, which observed the impact event. The goals of the mission, through the analysis of the ejected particles from the crater's surface following impact, were to provide answers to several fundamental questions about comets such as: what is the nucleus of the comet composed of? What depth would the crater, formed from the collision with the spacecraft impactor, reach? Where did this particular comet, Tempel 1, originate? [1] However, the impact between the spacecraft impactor and the comet produced a dust cloud that actually obstructed the fly-by probe's view of the resulting crater. Moreover, due to the nature of the event and particular resource and opportunity constraints, certain observations such as the geometry of the particle ejection plumes and curtains formed by the impact could not be observed. Thus, not only were scientists prevented from discerning the size of the crater

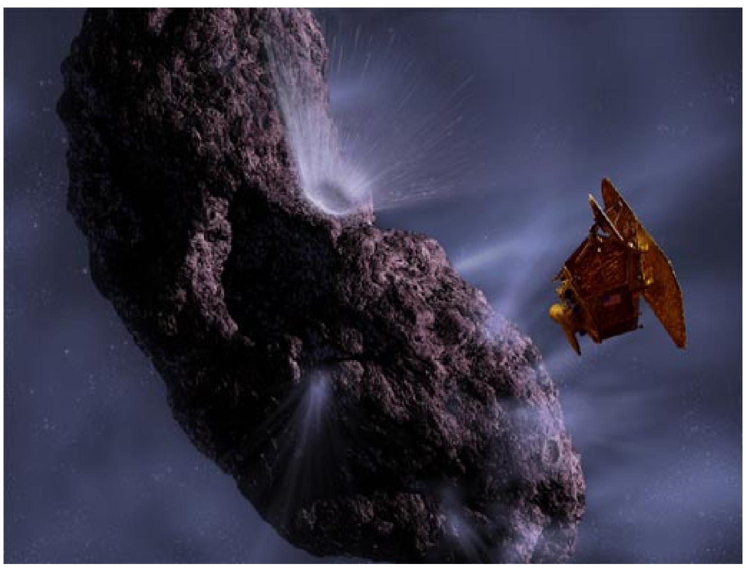

Figure 1: Artist Pat Rawlings' rendition of the Tempel 1 comet and the Deep Space impactor collision

but they were also unable to capture certain details of the impact event which would allow them to better analyze the dust cloud.

C Research Plan

From the photos taken by the fly-by probe of the Deep Impact event and observations made from simulation experiments, Dr. Schultz and his team have presented the idea that the impact between the impactor and the Tempel 1 comet, in terms of the particle ejecta, can be divided into three distinct phases [2].

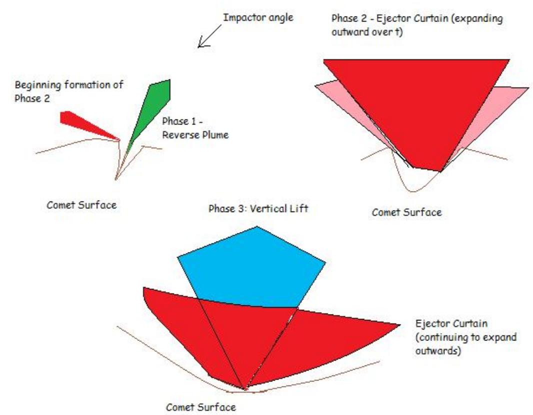

Figure 2: Representation of distinct phases during particle ejections following impact (as defined by Dr. Schultz and his team)

C.1 Research Plan: Establishing Particle Streams

We expand upon this idea and generalize it by breaking the impact event into phases represented by particle streams based on the following parameters: Time(t), time at which particles were ejected from the surface of the impacted body, Angle 0f ejection(θ), angle at which particles were expelled from the surface of the body (0 to 180 degrees), Position(x): location of particles relative to body core at specified time, t, and Azimuth of ejection angle (Φ): direction of ejecta (0 to 360 degrees). These parameters will then be incorporated into a rigorous equation which will be utilized to define the number of ejection streams for a given impact (and, thus, the number of phases).

C.2 Research Plan: Rendering Particle Ejection Streams

The purpose of the particle ejection streams is to provide the user with an informative visualization of the impact phases so as to better understand spaceborne impacts. Thus, it is necessary for certain elements/characteristics of the particle ejection phases to be encapsulated within the rendering process of each corresponding particle ejection stream in such a way that the user can readily identify these attributes throughout the visualization. We, therefore, present the idea of representing each particle stream as an analytically defined dynamical system and rendering this system utilizing advanced stream representations [3]. Through the use of "streamlines", "streamballs", "streamarrows", "anisotropic spot noise as streamline texture", and other such features, various components of each particle ejection stream as well as, possibly, whole streams, themselves, which might become occluded or not easily distinguishable

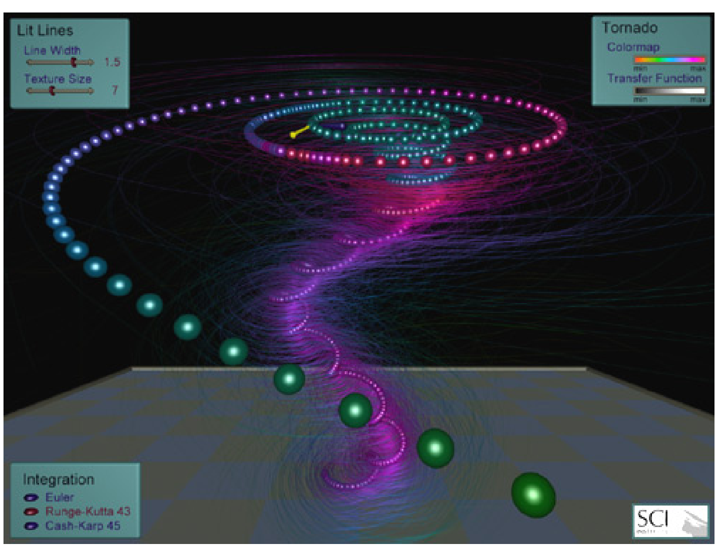

Figure 3: Example of tornado simulation application utilizing the "streamballs" rendering approach

amidst other elements of the visualization otherwise, will be completely identifiable [4]. This technique not only eliminates the potential of occlusion but also provides an effective means to visualize aspects of the data integral to the overall visualization.

C.3 Research Plan: Enabling Interactive Manipulation of Various Data and Impact Dimensions

In order to generalize the applications of our project, it is necessary for our tool to assume very little about the dynamics of the impact event. That is, while utilizing the NASA Deep Impact mission as an example to facilitate the development of certain aspects of our software is acceptable, we do not want to limit the application to just this specific event. As a tool which will aid in the planning of future "impact" missions, it must allow for a wide-range of user manipulation. For example, due to the vast amounts of resources committed to these "impact" missions as well as due to the lack of repeatability, it would be considerably beneficial to the planning process of these missions to devise a feature within our application that allows the user to, let's say, adjust the angle of impact for the impactor or the impact site. The question which then arises is: how do we account for the alterations in particle parameters resulting from these adjustments? We propose the idea of utilizing implicit particle flow visualization techniques [5] as well as incorporating the AGEIA PhysX SDK (Software Development Kit) and its base PPU (Physics Processing Unit) hardware into our OpenGL code base. The PhysX PPU will allow for real-time processing of the complex physical interactions occurring from impacted body/impactor collision as well as other collisions which take place throughout the environment while the implicit particle flow visualization techniques will provide an efficient means for rendering these interactions.

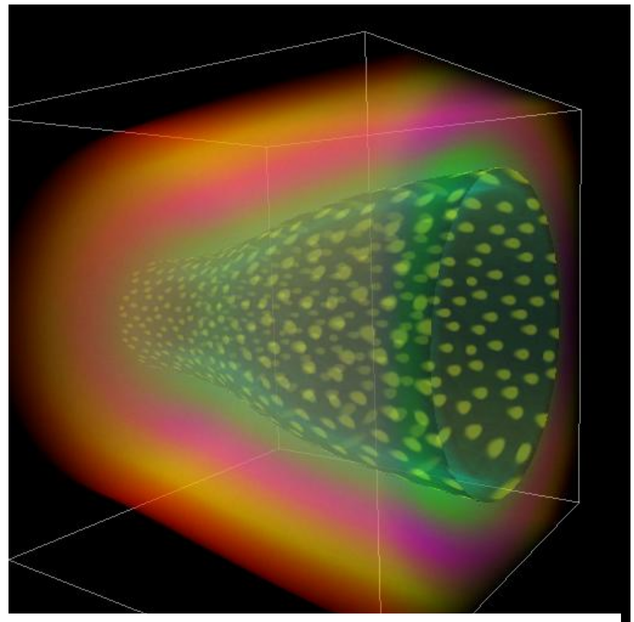

Figure 4: example of implicit flow visualization

D Significance

In terms of the visualization aspect, scientists will be able to visualize and test their models in three dimensions while at the same time manipulate various components of their data by working interactively with the system. From the scientific perspective, the advanced features of the tool will allow geologists and other scientists to reach a greater depth in their understanding of spaceborne collisions, mainly from a physics aspect, so that they may apply it to the design of future impact missions under NASA or elsewhere in order to more efficiently and precisely collect targeted data from these events. Furthermore, advancements in comet impact missions, alone, could solve the puzzles of the creation and evolution of our solar system and, perhaps, the universe.

E Related Work

The NASA Deep Impact mission was the first mission launched by NASA or any other space exploration organization in the international community to thrust an object at a comet and attempt to better understand the various characteristics of the comet through the analysis of the particles ejected from the surface following impact. Ergo, while considerable amounts of resources have been invested in the modeling, animation, and development of visualization tools for simulating large extraterrestrial body dynamics, there is only a relatively small amount of work, done exclusively for ad hoc purposes, that is at all relevant to our proposed research project. These works consist of filmed laboratory experimental simulations.

G Timeline

Week 1	Identify and obtain sufficient proficiency in OpenGL and PhysX SDK
Week 2	Generate static visualization of Deep Impact scene, incorporate Peter's mathematical model particle ejection vector data into simulation rendering
Week 3	Develop particle color-coded scheme for simulation rendering, begin work on application's particle stream phase distribution feature
Week 4	Continue work on particle stream phase distribution feature, integrate interactive visualization element
Week 5	Test application, compare and verify results with other simulation techniques, refine application based on feedback
Week 6	Implement final functional adjustments, complete refactorization of program code, and prepare final report and presentation

H References

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Volume Rendering of Time-Varying Earthquake Simulation Data

Brandon Nardone (PI), Terry Tullis (Collaborator)

Brown University, Providence, RI

Abstract

We propose to develop a tool that will visualize data generated from computer simulations of the Parkfield section of the San Andreas fault. This tool will aid in the understanding of the causality between seismic activity by making the spatial and temporal relationships more apparent.

Introduction

According to the United States Geological Survey, approximately 75 million people in 39 states face significant risk from earthquakes. They cost the United States $4.4 billion per year and this is projected to climb to $5.6 billion in the near future [1]. Due to the ever present danger that earthquakes pose to so many people, it is not unexpected that great efforts have been made to better understand this phenomenon. Specifically, much has been done to create and refine computer models of earthquakes of various scales to isolate why and how they happen at particular times and places.

Prof. Terry Tullis, along with many of his peers, is focusing on the Parkfield section of the San Andreas Fault. This area is particularly interesting to geologists given its rather unique behavior. Because it lies midway between a creeping section to the north and a locked section to the south. As a result of this, Parkfield has experienced six magnitude 6 earthquakes from 1857 to 1966 approximately every 22 years. Due to this cycle, great expense was taken beginning in the 1980s to construct a dense network of advanced monitoring instruments throughout the area. Prof. Tullis has created a computer model of this activity and hopes to use his results to investigate the causality between seismic activity through exploratory visual analysis of the spatial and temporal patterns in slip rates between plates in the earth captured at varying discrete time intervals. The ultimate goal is to use this understanding to better predict earthquakes.

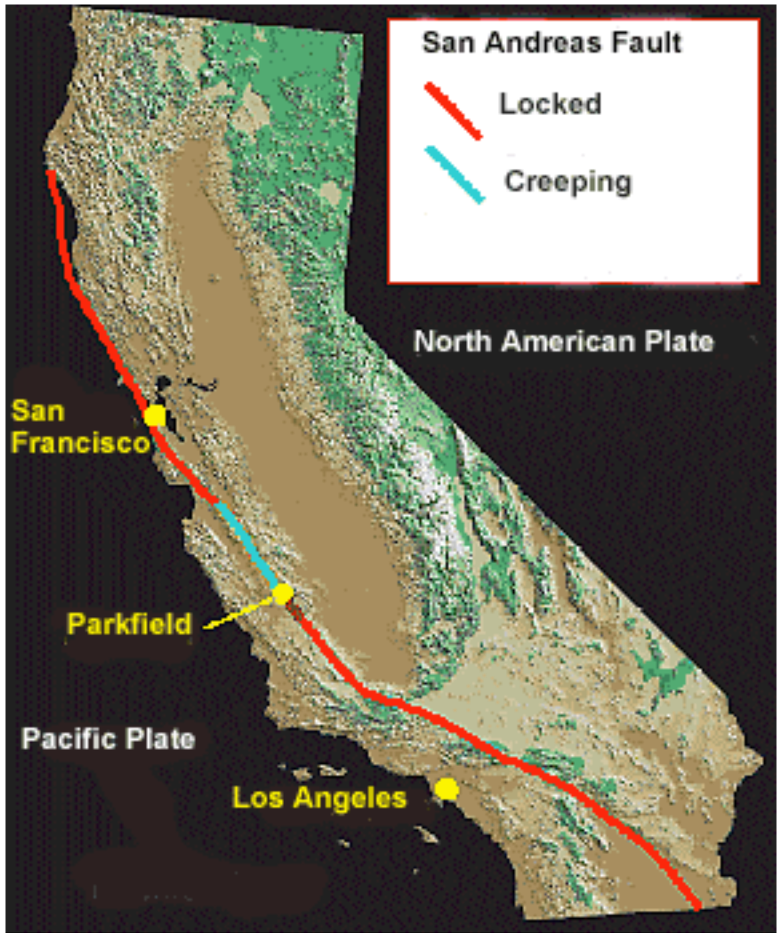

Figure 1: Location of Parkfield on the San Andreas Fault [2]

Research Plan

The data exists as non-uniformly distributed time slices of non-uniformly distributed two dimensional grids. Each cell on the grid represents the velocity on the fault at that location. The non-uniform grid is a result of Prof. Tullis and others' research into the adaptation of fast multipoling for use in earthquake modeling [3]. This is essentially increasing the level of detail as needed in particular regions for the simulation. This is useful for reducing complexity of computation by decreasing the number of cells with little to no activity. This is also fortunate from a visualization perspective as when it is time to render much of this uninteresting space is quickly and easily skipped.

We propose to visualize this scalar data over time with a volume rendering technique that is color mapped. Specifically, the volume rendering will consist of the discrete slices with investigation done into the utility of filling the space between each slice with a linear interpolation of each adjacent one.

In terms of color mapping, for each slice, a range of interesting values will be determined according to the local activity. This will be used when determining the appropriate coloration and transparency for a particular element so as to emphasize the higher activity regions at a local scale. This step will ensure that typical high velocity slip rates that tend towards an earthquake do not steal attention away from the activity in earlier time periods that are of interest in finding patterns that lead up to such an event.

Transparency of a cell is function of its velocity value as well as proximity to the current time slice. This will leave the current slice as the primary focus while also leaving surrounding data intact for patterns to be observed. This has the added benefit of having the “threads” of activity fade into and out of a bounding volume as they are generated and released dynamically (a necessity given the size of the data sets).

The application will be interactive to facilitate true exploration of the data set. The user will be able to zoom, rotate vary the speed that slices move through the bounding volume.

These visualization techniques and the application itself lend easily to other seismic activity data sets and research.

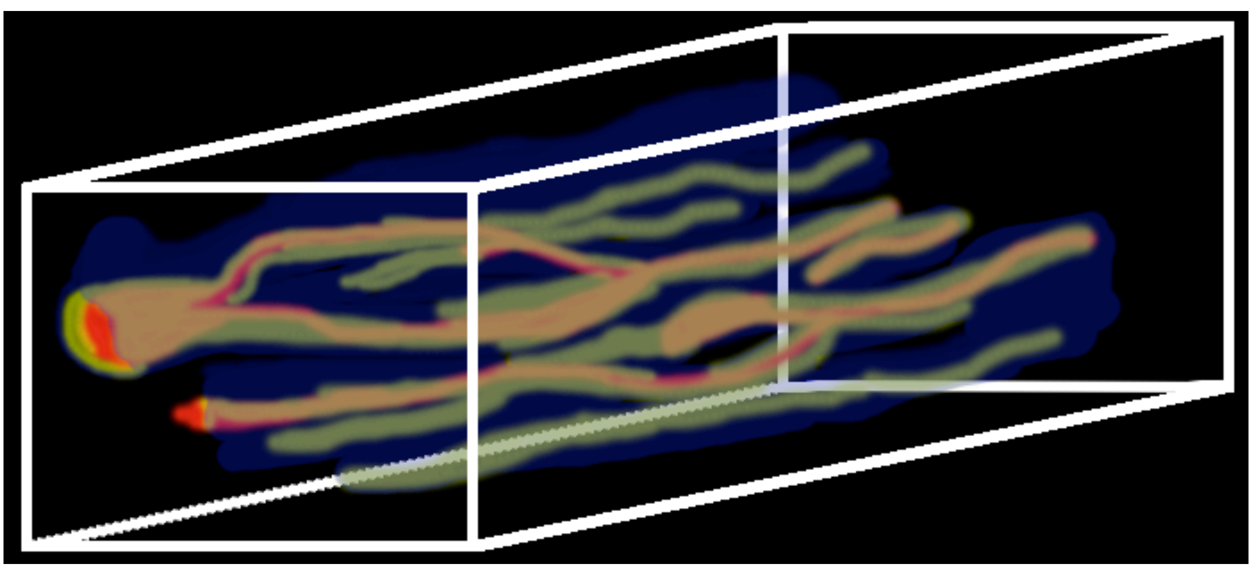

Figure 2: Concept illustration of the volume rendering of slip rates over time. Color and opacity are determined using the cell’s velocity as well as the current slice’s activity range of interest.

Related Work

Much work has been done on the visualization of seismic activity. Ma et al [3] visualized massive scale seismic wave propagation and Chopra et al [4] also visualized this type of simulation as well as researching the use of an immersive CAVE environment. These researchers approached similar problems in a related way through their use of the volume rendering of three dimensional simulation data over time.

Our visualization approach differs as a result of the distinct purpose which drives the need for such an application. The aforementioned research papers approach the problem in an effort to display what is happening. They are interested in the result and effects of the event. We are looking to discover why they happen. We are seeking to accentuate the temporal and spatial relationships through our dynamic color mapping and use of temporal information. In this way geologists will be aided through improved observations of simulation data.

Timeline and Milestones

Week 1: The proposed software architecture will be documented and the data loading will be implemented. We will meet with Terry to determine and acquire a good mixture of data sets that vary in size and activity.
Week 2&3: We will implement the volume rendering of the time slices. Static color mapping will be used.
Week 4: Dynamic color mapping will be implemented and analyzed.
Week 5: The application will be debugged, sped up to bring to at or near real time. We will evaluate its usefulness as well as potential future approaches/improvements
Week 6: We will write the final report to present our results and findings

The electronic deliverable of this endeavor will be made open source and available to all for use in research.

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From: Terry Tullis <Terry_Tullis@brown.edu>
Date: September 19, 2007 4:10:57 PM EDT
To: Brandon Nardone <bnardone@cs.brown.edu>
Cc: Terry Tullis <Terry_Tullis@brown.edu>
Subject: Files for you

Dear Brandon,

I really enjoyed meting with you this afternoon. I hope this project works out well and that this is the beginning of a enjoyable and productive relationship!

I attach 6 files. The first has 3 email exchanges between me and Cagatay that outline what we felt might be good things to do, and tells his comments at the end on the status and where his files are. The next two are those C++ files that read my data files. The one with bin in its name is the one that reads the time files in binary format. The final three are data files for the 715 element starting case (actually 712 elements - there are three boundary condition elements that are not in the files, so sometimes I am inconsistent in how I name them).

grib.geob.terry -

this is the ASCII file that has the geometry in it and is read by both programs. It has to be renamed grid.geom.terry to work with the Amira module that is created by the TerryTullisGrid.cpp file - its current name (with b's in it) is designed to be read by the TerryTETbinGrid.cpp file. I don't totally understand how much of that naming is referred to in the C++ files and how much of it is picked up by Amira from other resource file that have some of the file name components listed in them (i.e. timb.terry and geob.terry for the binary case and time.terry and geom.terry for the ASCII case).

grid.time.terry - this is the ASCII time file for 101 time steps.

grib.timb.terry - this is a binary time file for 200 steps (I couldn't find one for 100 time steps).

Please let me know if you need anything else. Hopefully this should get you started!

Cheers,
Terry

Brandon Nardone

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SKILLS

Professional development experience with C, C++, Python, Ruby. PHP, SQL, Rails, Django, OpenGL, MySQL, PostgreSQL, Apache, Mongrel, Lighttpd. Academic and personal experience with Java, C#, Perl, Win32, DirectX, Scheme, Common Lisp.

Comfortable in Mac OS X, Gentoo Linux and Windows XP.

PROFESSIONAL EXPERIENCE

Software Engineer, Brontes Technologies, Woburn, MA/3M, Lexington, MA — Jan ’05 - Aug ‘07

EDUCATION

Wentworth Institute of Technology, Boston, MA — B.Sci. CS 2006, Magna Cum Laude

Association of Computing Machinery — Treasurer, Presenter
Linux User Group — Member
Artificial Intelligence Club — Member, Presenter
Capstone Project: 3D Multi-Player Game

Brown University, Providence, RI — M.Sci. CS, expected 2009

Real-time Visualization of Deep Space Impact Models

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Peter H. Schultz[2345], Brendan Hermalyn[2] (Collaborators)

[1]Brown University, Department of Computer Science
[2]Brown University, Department of Geological Sciences
[3]Lunar and Planetary Institute Planetary Image Facility
[4]Northeast Planetary Data Center
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Abstract

Mathematically rigorous physical models of the collision event from NASA's 2005 *Deep Impact* mission are not currently available, hampering efforts to recreate the experiment in a laboratory setting. We propose an interdisciplinary project to develop an interactive tool for visualizing mathematical models of the impact. Given the ability to manipulate visualized models in real time, geologists can use inverse methods to derive accurate physical models of the event.

Introduction

As some of the primordial "building blocks" of our solar system, comets represent enormous potential for discovery. Loosely-packed bodies of ice and rock, they are believed to be remnants of the solar nebula, the interstellar cloud from which our solar system formed. A clearer understanding of the composition of comets will lead to better insight into the early years of our solar system and the formation of the planets [1]. With this in mind, NASA has undertaken a number of missions to glean information from comets passing through our neighborhood, most often (in the case of *Giotto* and *Stardust*) observing the surface of the cometary nuclei from a distance. But in the case of *Deep Impact*, investigators set out to "excavate" a comet by colliding a coffee table-sized impactor with the nucleus of comet 9P/Temple, while a Volkswagon-sized observatory probe recorded the event in stereo from close range [2].

The problem since the mission has become deriving from the observed data the success of the event and the characteristics of the collision—information that will ultimately lead to the composition, structure, and age of the comet. It is necessarily an "ill-posed" problem, as the methods of collecting data during the mission were limited by the technology, cost, timing, and—obviously—inability to repeat the experiment under the same conditions. Geologists thus seek to define the event with a rigorous mathematical model, which will then allow them to simulate and recreate this and other impact events in a laboratory setting [3].

Problem Statement

Dr. Peter Schultz, Director of the Northeast Planetary DataCenter at Brown University, seeks to derive this physical model by comparing a photometric but mathematically rigorous visualization of the event with the observed data from the mission record. Because of the limitations of the observed data, an inverse method is appropriate for obtaining the model parameters.

Our primary goal is to develop a photometric yet robust tool for the visualization of parametric definitions of the different stages of the impact event. Dr. Schultz's team has developed a heuristic that they intend to use as a starting point. With our tool, they will be able to visualize their approximation of the impact and compare it to the only experimental data set available, to subsequently modify and revise their heuristic accordingly, arriving inversely at an accurate model.

Research Plan and Methodology

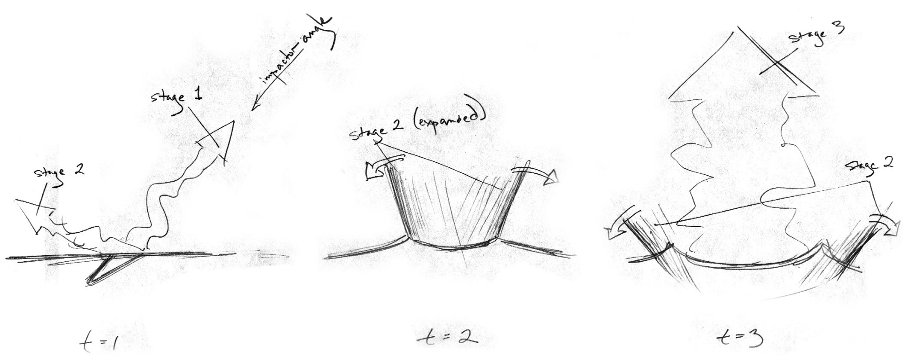

Figure 1: Illustration of several time intervals during an impact event. Note that a component such as "stage 2" can alter dramatically over the lifespan of the event [3].

Beyond static components, such as the cometary nucleus, light source, and the trajectory of the probe, we define the impact simulation as an arbitrary number of discrete particle systems.

Defining Particle Systems

We break the stages of the impact into discrete, individually-defined components, which serve as the input for our software tool. For the purposes of this visualization, we will treat each component as a separate and noninteracting particle system—that is, these components do not influence each other's behavior, but may affect each other's visibility. Each is defined as a parametric equation with a free parameter for time, *t*, and a rigorous definition for a form that is then time-dependent. The form is rarefied into a particle field by scattering an arbitrary number of particles within. These are clustered naively, but constant in number for a given form over its lifespan. The volume of the form thus defines the particle density, and consequently the opacity, at a given time, *t*.

Rendering Particle Systems Photometrically

The nature of the verification method required—a comparison with visual data—necessitates a photometrically accurate output. While optical comparison may be sufficient in early stages of the reduction [4], a more rigorous comparison with the photographic record is required in later steps, including comparison with thermal evolution models and post-impact light curves. In particular, components, or "plumes," of the impact not directly observable in the current viewport must be inferred via indirect methods, such as shadow on other components. As a result, photometry and imaging results, including photometric shadow and light sources, are crucial [5], and particles must be rendered with real-time ray tracing.

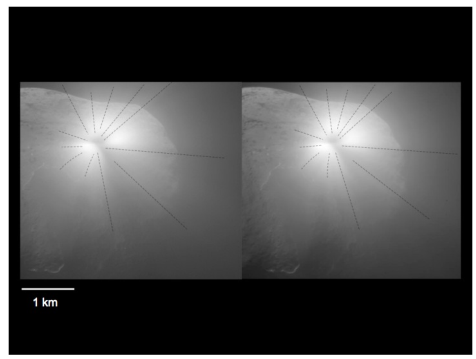

Figure 2: Photography from the observer probe demonstrates a shadow being cast on the "curtain" component of the impact (lower right), likely caused by a plume at the center not seen directly.

Reduction of the Model

The inverse solution begins with an arbitrarily high number of parametrically-defined components in the impact visualization. Separation of the impact event into a high number of simple components will allow easier fine-tuning of the tool and rapid development of accurate physical models for each component. When comparison with the photographic record and thermal evolution models [6] confirm the accuracy of the components, we reduce the model by combining two or more components to derive a more accurate parametric, and then repeat the process until all components have been combined into one accurate event model.

Novelty and Significance

Existing visualizations of the Deep Impact event are, to put it bluntly, unscientific and not applicable. Much more rigorous maths must be applied to the problem before accurate models can be derived. Current visualizations of the mission, such as Dan Maas's predictive animation, are unsuitable for manipulation and photometric comparison. We intend to expand the capabilities of our framework far beyond the existing animations, by converting primitive abstractions into

Figure 3: Existing simulations dramatically simplify the impact event, despite being widely circulated for analytical purposes. This visualization shows only one impact component.

true particle systems, building the capacity for multi-component impact visualizations, and allowing for asymmetrical components. We will also allow for a manipulable optical depth with our technique of varying particle density as a function of the volume of the plume at a given time.

From a visualization standpoint, we intend to make use of several newly-available techniques to achieve a useful balance between realism in the visualization and a generality that will allow it to be flexible and manipulable in real time. As recently as 2004, Chris Johnson of the Univeristy of Utah identified both time-dependent visualization and a failure to efficiently use existing hardware architectures as some of the "top scientific visualization research problems" today. We plan to make use of OpenRT [9], a real time ray tracing package, which will allow us to apply photometric realism to an interactive visualization in a way that has not been attempted. We will then extend the interactive capacity of the framework, creating a much more generalized tool for evaluating the anatomy of space-borne collisions.

Timeline and Milestones

Weeks 1 – 2: Familiarize ourselves with the OpenRT-API. Construct constants, including the structure of the comet, the angle and intensity of light sources, and the trajectory of the probe based on calculations provided by Dr. Schultz. Milestone: Noninteractive simulation of static elements based on mission telemetry.

Week 3: Translate existing primitive implementations into the OpenRT framework; extend shape definitions to allow for particle field representations, optical depth derived from particle density, forms asymmetrical along the impact normal, and layers in surface composition. Milestone: "Special edition" of Dan Maas' naïve animation, displaying similar functionality, but with our new framework.

Week 4: Develop a framework for inserting and defining an arbitrary number of impact event components with a parametric representation. Milestone: Working beta for users to test with their own parametric equations.

Week 5: Develop a basic interface allowing interaction with the viewport during real-time ray tracing.

Week 6: Use the tool in conjunction with Dr. Schwartz to derive a heuristic approximating the impact event. Milestone: Final abstract and final presentaion/demonstration.

Related Work

Prior visualization work on *Deep Impact*, as described above, seems relegated to less rigorous scientific modeling, and demonstrates the need for a visualization from which a scientific model can be ascertained.

By sacrificing the interactivity of the visualization, other avenues offer versatile solutions for visualizing porous models. K. Wnnemanna, et al, offer a new use of hydrocode for modeling cometary impact in particular. Despite the potential advantages of hydrocode applications in crater formation, the treatment of porous materials still poses large problems. The authors deal with the collapse of pore space using a function based on strain as opposed to pressure, the more conventional treatment. They present a simple and intuitive 4-parameter model, found to be particularly well-suited for "highly dynamic impact experiments. While we have not pursued this avenue, it will be interesting to see its application on larger models [10].

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A Quantitative Metric for White Matter Integrity

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4 October 2007

Abstract

We propose to define a metric for white matter integrity between regions of interest inside the brain, which will quantify properties of the underlying physiology in a consistent manner regardless of the means of computing it. This will facilitate precise communication among researchers and quantitative analysis of white matter pathologies. We will extend existing brain visualization software to compute and display this quantitative information.

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1 Background

The study of white matter tracts in the brain generally concerns itself with two properties: *connectivity* and *integrity*. *Connectivity* describes the structure and organization of the white matter, answering the question "are two given regions directly connected to each other by a white matter tract?" with a binary response: yes or no. The connection between two regions may, however, be strong or weak, and it is this variation that the concept of *integrity* addresses. In many psychological and neurological pathologies, connectivity and even gross neuroanatomy may remain the same while the integrity of particular structures degrades [2, 3, 7, 9, 13].

Diffusion-weighted magnetic resonance imaging (henceforth dw-MRI) is a non-invasive technique for measuring the directionally dependent diffusion of water through tissue. In the white matter of the brain, water diffuses anisotropically in a manner correlated to the orientation and physiological properties of the axons within each sampling region. Therefore we may infer connectivity and integrity characteristics of the white matter from dw-MR images [1]. Most work on analyzing dw-MR images so far has concentrated on white matter *tractography*, a visual representation of connectivity that mimics the appearance of the brain [11].

Tractography is an appropriate and maturing method for studying connectivity in healthy as well as pathological brains, but integrity, while an important feature of white matter tracts, remains only loosely defined. Studies of integrity based on dw-MRI have devised many ad-hoc qualitative metrics for this property, including the dimensions of tractography results and volume averages of image-derived values, which relies on a priori knowledge of the location of a white matter bundle of interest [8, 2, 3, 7, 9, 13]. These metrics are incomparable to each other and do not have a clear meaning with respect to the underlying biological system of the brain, detracting from the ability of researchers to communicate their results to each other and to precisely correlate integrity variations with white matter pathologies.

2 Aims

We propose to define a quantitative metric for white matter integrity that is motivated by the physiological properties of biological tissue. Such an integrity metric is independent of how the measurement is performed. By analogy, the definition of a meter is fixed; one can determine that something is fifty meters meters tall by putting a tape measure next to it, looking at it through a sextant, or measuring the amount of time it takes for a marble to fall from the top of it to the bottom. Similarly, the notion of tract integrity is an absolute one, which has a uniform meaning whether it is measured by direct computation on diffusion MR images, by sampling in a tractogram, by injecting chemical tracers, or by an actual brain biopsy.

We also propose to implement the computation of this metric by two different algorithms and to integrate these algorithms into an existing dw-MRI visualization software package, BrainApp. The first algorithm is a Monte Carlo simulation of water diffusion between two regions of interest that relies only on the raw dw-MR images. A similar approach from 2002 that concerned itself with probabilistic connectivity provides insight into mapping earlier algorithmic work on related problems to the field of white matter analysis [12]. The fluid dynamics community has examined diffusion equations for decades, and our algorithm will draw inspiration from the early work in this field [10]. The 3D graphics rendering community in computer science has also traveled this path in the development of efficient algorithms for light transport computations [6, 14, 15]. More recent work on efficient algorithms for light transport within participating media should be relevant to making our own algorithm run quickly [4, 5].

The second algorithm is a refinement of previous tractography-based integrity analyses [8]. We will determine the relationship between such dw-MRI-derived values as fractional anisotropy and diffusion tensor trace, which are commonly used as qualitative indicators of integrity [7, 9], with our metric, and use selected tracts of interest to compute integrity over the relevant volume.

2.1 Benefits

A universal, biologically-motivated integrity metric would allow neurology researchers to communicate their results with concrete, qualitative values. White matter integrity is already an important quality examined by many functional studies in the field, but comparison and aggregation of results is difficult when they are defined in incompatible ways. Extending an existing visualization program for white matter exploration to include algorithms to compute this metric would allow researchers an intuitive and straightforward way to gather their derived data.

2.2 Plan

We plan to produce concrete deliverables for each of the aims of the project.

- **Week 1.** Mathematical definition of integrity metric.
- **Week 3.** Single-ROI tract selection and dual-ROI selection in BrainApp.
- **Week 4.** Integrity computation and display by diffusion simulation with two ROIs.
- **Week 5.** Integrity computation and display by tract characteristics with one ROI.
- **Week 6.** Final report.

2.3 Facilities

The graphics workstations in the Computer Science department's graphics laboratory are sufficient for the computational needs of this project.

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Professional Preparation

2006 Duke University — Durham, NC, USA
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Appointments

2006—present Brown University — Providence, RI, USA
PhD Student in Computer Science Department

- Research on scientific visualization workflows in virtual reality
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Training, Software Test, and Engineering Intern

- Development with computer vision algorithms for scene reconstruction
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- Source code organization and optimization
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- Software testing
- Network and hardware maintenance

2004—2006 Duke University — Durham, NC, USA
Undergraduate Teaching Assistant in Computer Science Department

- **2004** Software Design
- **2005** Graduate Numerical Analysis; Computer Graphics
- **2004** Discrete Mathematics

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Publications

J. Miles, D.F. Keefe, D. Acevedo, F. Drury, S.M. Swartz, and D.H. Laidlaw. Teaching Science in Virtual Reality with a Freehand 3D Illustration. Poster at IEEE InfoVis 2007.

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Computer Science Researcher at Brown University — Providence, RI
Summer 2006, June 2007 - present

- Developing a software package that will allow scientists to view and interact with high resolution videos of 3D skeletal models.
- Responsible for implementing, testing, and optimizing various software tools used to capture and analyze motion data.
- Research funded by the Keck Foundation

Instructor of Mathematics at Groton School — Groton, MA
June 2006 - June 2007

- Taught AP Calculus, Geometry, and Algebra 2/Trigonometry, as well as an introductory programming course.
- Served as assistant coach to the varsity basketball and baseball teams.

Software Engineer at Mad Doc Software, LLC. — Andover, MA
June 2005 - June 2006

- Responsible for creating and maintaining several game systems for the PC and Microsoft XBox 360 title *Star Trek Legacy*, published by Bethesda Softworks.
- Developed various modes of online play, maintaining network-safe code.
- Aided in the communication between designers and developers, regularly presenting new ideas and algorithms to the production team.

Academic Honors

- Member of Pi Mu Epsilon (Mathematics Honor Society) and Phi Beta Kappa.
- Awarded the Gertrude McBrien Medal as the top mathematics student at Holy Cross.
- Awarded a Summer Research Fellowship in Science and Mathematics from the Council on Undergraduate Research.
- Selected to attend the IAS/Park City Mathematics Institute 2004 Research Experience for Undergraduates.

Computer Skills

Languages:	Proficient in: C/C++, Java, XML, HTML, Javascript Familiar with: Perl, Lua, PowerPC Assembly
Software:	Microsoft Visual Studio .NET, CodeWarrior, Perforce, Subversion, CVS, Matlab, Microsoft Office
APIs:	OpenGL, DirectX 9/9.5, SDL, G3D, VRG3D

Research Interests

Medical imaging, physically-based rendering, real-time graphics.

Revised 7 April 2006

CURRICULUM VITAE

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EDUCATION

Undergraduate	Manhattanville College September 1978 – December 1979 (transferred)
	University of Rhode Island Psychology, Bachelor of Arts January 1980 - May 1982 Summa cum laude
Graduate	University of Rhode Island Clinical Psychology, Master of Arts, September 1994 - May 1998
	University of Rhode Island Clinical Psychology, Doctor of Philosophy May 1998 - May 2001

PRE- AND POST-DOCTORAL TRAINING

Pre-Doctoral Internship	Malcolm Randall Veterans Affairs Medical Center, Gainesville, FL Neuropsychology/Geropsychology Internship September 1999 – August 2000
Post-Doctoral Fellowship (Research)	Dementia Research Fellow (T32, National Institute on Aging) Department of Psychiatry and Human Behavior Brown Medical School Providence, RI September 2003-present
Post-Doctoral Fellowship (Clinical/Research)	Neuropsychology Fellow Department of Psychiatry and Human Behavior Brown Medical School (Butler Hospital) September 2000 – August 2002

POSTGRADUATE HONORS AND AWARDS

July 2002 — Travel Fellowship to The 8th International Conference on Alzheimer's Disease and Related Disorders, Stockholm, Sweden

June 2003 — National Institute on Aging Summer Research Institute, Airlie, VA

July 2003 — National Institute of Mental Health/University of California San Diego Summer Research Institute, Los Angeles, CA

August 2003 — Travel Fellowship to The First Congress of the International Society for Vascular Behavioural and Cognitive Disorders (VAS-COG), Göteborg, Sweden

July 2004 — Travel Fellowship to The 9th International Conference on Alzheimer's Disease and Related Disorders, Philadelphia.

June 2005 — Travel Fellowship to the 2nd Congress of the International Society for Vascular Behavioural and Cognitive Disorders (VAS-COG), Florence, Italy.

June 2005 — Student representative to the Scientific Committee, International Society For Vascular Behavioural and Cognitive Disorders

MILITARY SERVICE — None

PROFESSIONAL LICENSES AND BOARD CERTIFICATION

Rhode Island
Psychology, PS00796
Awarded 12 December 2002

ACADEMIC APPOINTMENTS

Assistant Professor of Psychiatry & Human Behvior
Brown Medical School
September 2005

HOSPITAL APPOINTMENTS

Neuropsychologist
Providence Veterans Affairs Medical Center
September 2005

Staff Psychologist
Director of Clinical Research, Memory & Aging Program
Butler Hospital
September 2002 – August 2003

Research Psychologist
Rhode Island Hospital
September 2002 – August 2003

Staff Neuropsychologist
Providence Veterans Affairs Medical Center
September 2005 – present

HOSPITAL COMMITTEES

Institutional Review Board (alternate member)
Butler Hospital
2003-present

Institutional Review Board (alternate member)
Providence VA Medical Center
2006-present

MEMBERSHIP IN SOCIETIES

International Society for Vascular Behavioural and Cognitive Disorders – Students
American Psychological Association
American Academy of Neuropsychology
International Neuropsychological Society
Rhode Island Psychological Association
Phi Beta Kappa

ORIGINAL PUBLICATIONS IN PEER-REVIEWED JOURNALS

1. Correia, S, Faust, D, & Doty, R. (2001). A re-examination of the rate of vocational dysfunction among patients with anosmia and mild to moderate closed head injury. *Archives of Clinical Neuropsychology,* 16, 477-488.
2. Salloway S, Boyle P, Correia S, Malloy P, Cahn-Weiner D, Schneider L, K. Krishnan R, & Nakra R. (2002). The relationship of MRI subcortical hyperintensities to treatment response in a placebo-controlled trial of sertraline in geriatric depressed outpatients. *Am J Ger Psych*, 10, 107-111.
3. Salloway S, Gur T, Berzin T, Zipser B, Correia S, Hovanesian V, Fallon J, Kuo-Leblanc V, Glass D, Hulette C, Rosenberg C, Vitek M, & Stopa E. (2002) Effect of APOE genotype on microvascular basement membrane in Alzheimer's disease. *J Neurol Sci*, 203-204, 183-187.
4. Salloway S, Correia S, Boyle P, Malloy P, Schneider L, Lavretsky H, Sackheim H, Roose S, & Krishnan K.R.R. (2002). MRI Subcortical Hyperintensities in Old and Very-Old Depressed Outpatients: The Important Role of Age in Late-Life Depression. *J Neurol Sci*, 203-204, 227-233.
5. Rymer S, Salloway S, Norton L, Malloy P, Correia S, & Monast D. (2002). Contributions to caregiver burden in Alzheimer's disease: Awareness of deficit and behavioral disturbance. *Alzheimer's Disease and Associated Disorders*, Oct-Dec; 16(4):248-53.
6. MacLean A, Correia S, Woods R, Stopa E, Cortez S, Alderson L, Salloway S. Spontaneous lobar hemorrhage in CADASIL. J Neurology Neurosurgery and Psychiatry, 2005.
7. Grant JE, Correia S, Brennan-Krohn T, Laidlaw D. White matter integrity in kleptomania: A pilot study. Psychiatry Research: Neuroimaging (in press).
8. Malloy P, Correia S., Stebbins G., & Laidlaw DH. Neuroimaging of white matter: A review of methods and neuropsychological correlates in aging. Invited review paper, Archives of Clinical Neuropsychology. The Clinical Neuropsychologist (in press)

BOOKS AND BOOK CHAPTERS

Correia S, McNicoll L. Dementia. Chapter in *Ferri's Geriatric Advisor*, 1st edition. Philadelphia: Elsevier (in press).

OTHER NON-PEER REVIEWED PUBLICATIONS

Salloway S, Correia S, Peck J, & Harrington C. (2002) Dementia with Lewy Bodies: A Diagnostic and Treatment Challenge. *Medicine and Health/Rhode Island*, 85, 207-209.

PUBLICATIONS SUBMITTED OR IN PREPARATION

1. Grant JE, Correia S, Brennan-Krohn T, Schulz C. White matter integrity in borderline personality disorder with self-injurious behavior: a pilot study. *American Journal of Psychiatry* (submitted).
2. Salloway S, Correia S, Richarson S. Key Lessons Learned from Short-Term Treatment Trials of Cholinesterase Inhibitors for Amnestic MCI. *International Psychogeriatrics* (submitted).
3. Lee S, Correia S, Tate D, Paul R, Zhang S, Salloway S., Malloy P, Laidlaw DH. Quantitative metrics for white matter integrity based on diffusion tensor MRI. *Neuroimage.* (submitted)
4. Correia S, Salloway S. Treatment of vascular dementia. *Alzheimer's Disease and Associated Disorders* (submitted).
5. Correia S & Faust D. The potential clinical utility of methods for estimating prior standing on specific cognitive domains: An illustration study. *The Clinical Neuropsychologist* (submitted).
6. Salloway S, Correia S, Malloy P, et al. Clinical response to donepezil in patients with vascular dementia: Relationship to lesion location (in preparation)
7. Salloway S, Correia, S, Mahableschwarkar A, Brashear R. Differential efficacy of galantamine in patients with dementia and cerebrovascular disease: a sub-analysis by CVD lesion subtypes (in preparation).
8. Correia S, Salloway S, Malloy P. Systolic Blood Pressure Variability and Subcortical Hyperintensities in Patients with Mild-To-Moderate Alzheimer's Disease (in preparation).
9. Correia S, Brennan-Krohn T, Zhang S, Laidlaw DH, Malloy P, Salloway S. Diffusion-tensor imaging and executive function in mild cognitive impairment and vascular cognitive impairment. (in preparation)

<u>ABSTRACTS</u>

1. Salloway S, Boyle P, Correia S, Malloy P, Cahn-Weiner D, Scheider L, Krishnan KRR, Nakra R, Sackeim H, Roose S, & Lavretsky H. (2002). MRI Subcortical Hyperintensities and Response to Sertraline and Citalopram in Geriatric Outpatients with Major Depression. Presented at the 15th Annual Meeting of the American Association of Geriatric Psychiatry, Orlando, FL.
2. Salloway S, Boyle PA, Correia S, Malloy PF, Cahn-Weiner DA, Schneider L, & Krishnan KRR, Nakra, R. (2002) MRI Subcortical Hyperintensities and Response to Sertraline in Geriatric Depressed Outpatients. Presented at the 2nd Annual Conference on Vascular Dementia, Salzburg Austria.
3. Correia S, Salloway S., Boyle, P Malloy P, Cahn-Weiner D, Schneider L, Krishnan RR, Nakra R. (2002) Relationship of subcortical hyperintensities to treatment response in young and old elderly with outpatient geriatric depression: Results of two placebo-controlled trials. Abstract. Presented at the 8th International Conference on Alzheimer's Disease and Related Disorders, Stockholm, Sweden July 2002. *Neurobiology of Aging*, 23, abstract #598.
4. Boyle PA, Malloy PF, Salloway S, & Correia S. (2002) Functional Consequences of Subcortical White Matter Changes in Alzheimer's Disease. Abstract. Presented at the 8th International Conference on Alzheimer's Disease and Related Disorders, Stockholm, Sweden July 2002. *Neurobiology of Aging*, 23, abstract #1803.
5. Correia, S. & Faust, D. (2002). The potential clinical utility of methods for estimating prior standing on specific cognitive domains: An illustration study. Poster. Presented at the 22nd National Academy of Neuropsychology Conference, Miami, FL, September 2002.
6. Correia S, Salloway S, Roman G. (2003) Critical review of the NINDS-AIREN criteria for vascular dementia. American Academy of Neurology 55th Annual Meeting, April 2003, Honolulu. *Neurology* 2003;60:A377-8

7. Salloway S, Malloy P, Correia S. A comparison of the cognitive benefits of donepezil in patients with cortical versus subcortical vascular dementia: a subanalysis of two 24-week, randomized double-blind, placebo-controlled trials. American Academy of Neurology 55th Annual Meeting, April 2003, Honolulu. *Neurology* 2003;60:A141-2.
8. Correia S, Salloway S, Belanger H, Nassery S, Malloy P, Drodge S (2003). Ambulatory Blood Pressure Monitoring in Alzheimer's Disease Patients with High and Low Degree of Subcortical Hyperintensities. Poster. Presented at the First Congress of the International Society for Vascular Behavioural and Cognitive Disorder, Gothenburg, Sweden, August 2003.
9. Laidlaw DH, Zhang S, Bastin ME, Correia S, Salloway S, Malloy P. (2004) Ramifications of isotropic sampling and acquisition orientation on DTI analyses. Accepted poster. International Society for Magnetic Resonance in Medicine, 12th Scientific Meeting and Exhibition, May 15-21, Kyoto Japan.
10. Correia S, Salloway S, Malloy P, Song C, Li R. (2004) Systolic Blood Pressure Variability and Subcortical Hyperintensities in Patients with Mild-To-Moderate Alzheimer's Disease. Poster. 9th International Conference on Alzheimer's Disease and Related Disorders, July 17-22, Philadelphia. Abstract P2-182 *Neurobiology of Aging*, 25(S2), S278
11. Correia S, Zhang S, Laidlaw D, Malloy P, Salloway S. Diffusion-tensor imaging: linear, planar, and spherical diffusion in CADASIL. Poster. 9th International Conference on Alzheimer's Disease and Related Disorders, July 17-22, 2004, Philadelphia. Abstract P2-232 *Neurobiology of Aging*, 25(S2), S298.
12. Brennan-Krohn T, Correia S., Zhang S, Laidlaw D, Malloy P, Salloway S. Diffusion-Tensor Imaging and Executive Function in Vascular Cognitive Impairment. Poster. International Society of Magnetic Resonance in Medicine, Workshop on Aging Connections: Advanced MRI of Age-Related White Matter Changes in the Brain, October 21-23, 2004, Boston.
13. Correia S. Diffusion-Tensor Imaging: Executive functioning in subcortical ischemic vascular disease and mild cognitive impairment. Paper Presentation. 33rd Annual Meeting of the International Neuropsychological Society, St. Louis, MO February 2005..
14. Correia S, Brennan-Krohn T, Schlicting E, Zhang S, Laidlaw D, Malloy P, Salloway S. Diffusion-tensor imaging in vascular cognitive impairment and mild cognitive impairment: relationship with executive functioning. Accepted abstract. 2nd Congress of the International Society for Vascular, Cognitive and Behavioural Disorders (VAS-COG), Florence, Italy June 8-12, 2005.
15. Grant JE, Correia S, Brennan-Krohn T. White matter integrity in kleptomania: a pilot study. Scientific Abstracts, American College of Neuropsychopharmacology 44th Annual Meeting. Kona, Hawaii: ACNP, 2005
16. Correia S, Lee S, Malloy P, Mehta N, Zhang S, Salloway S, Laidlaw DH. Diffusion-Tensor MRI Tractography Methods For Assessing White Matter Health And Its Relationship To Cognitive Functioning. Poster. International Neuropsychological Society 34th Annual Meeting, Boston, February 2006.
17. Zhang S, Correia S, Tate DF, and Laidlaw DH. Correlating DTI fiber clusters with white matter anatomy. Oral Presentation. 14th ISMRM Scientific Meeting & Exhibition, Seattle, Washington, May 2006.
18. Lee SY, Correia S, Tate DF, Paul RF, Zhang S, Salloway SP, Malloy PF, and Laidlaw DH. Quantitative Tract-of-Interest Metrics for White Matter Integrity Based on Diffusion Tensor MRI Data. Clinical Focus Presentation. 14th ISMRM Scientific Meeting & Exhibition, Seattle, Washington, May 2006.

INVITED PRESENTATIONS

Diffusion-Tensor Imaging: Basics and application to subcortical ischemic vascular disease. Division of Orthopaedic Engineering Research, Department of Orthopaedics, University of British Columbia/Vancouver Hospital, Vancouver, BC, CANADA, August 2004.

Diffusion-Tensor Imaging: A new MRI technique for characterizing white matter health. Grand Rounds: Department of Psychiatry. St. Luke's Hospital, New Bedford, MA. May 3, 2005.

White Matter Aging: Imaging and cognition. Colloquim presentation. Mental Health and Behavioral Sciences Service, Providence Veterans Affairs Medical Center, Providence, RI November 16, 2005.

EDUCATIONAL VIDEOTAPES

Rater training videos: Demonstration of cognitive and behavioral test administration for clinical trials rater-training. (4 videos)

Pharmastar, Inc., 2003-present
Assessments: Mini-mental state exam (MMSE), Alzheimer's disease assessment scale-cognitive (ADAS-Cog), clinical dement rating scale (CDR), Rey Auditory Learning Test, Logical Memory I & II from Wechsler Memory Scale – Revised.

GRANTS(Active)

1. Working memory and frontal white matter integrity in mild cognitive impairment.
   Role: Principal Investigator
   Funding Source: Alzheimer's Association; Young Investigator Award (NIRG-03-6195)
   Project: Uses diffusion-tensor imaging and cognitive testing to examine frontal systems integrity in patients with mild cognitive impairment.
   $100,000
   November 1, 2003 – October 31, 2006.

2. Advanced quantitative diffusion-tensor imaging metrics for clinical application.
   Role: Investigator
   Funding Source: Brown Vice President for Research Seed Grand (PI: David Laidlaw, Ph.D.)
   Project: This project will develop new interactive tools for rapid selection and quantification of specific white matter pathways for correlation with clinical status.
   $100,000
   September 2005 – August 2007

3. Aging brain: DTI, subcortical ischemia, and behavior.
   Role: Investigator
   Funding Source: NIA PAR-03-056 (PI: Stephen Salloway, MD)
   Project: This project uses diffusion-tensor imaging to investigate changes in the integrity of frontal systems white matter on executive function and behavior in patients with genetic and sporadic forms of subcortical ischemic white matter disease.
   $100,000
   June 2005 – May 2007

4. Diffusion-tensor and perfusion-weighted MRI for improved detection of white matter injury in paitents with hypertension.
   Funding Source: Brown Department of Diagnostic Imaging (PI: Jerrold Boxerman, MD)
   Role: Co-Principal Investigator
   Project: Uses advanced neuroimaging to examine the impact of hypertension on subcortical white matter and its relationship to cognition.
   $15,000

5. Diffusion-tensor and perfusion-weighted MRI type 2 diabetes.
   Funding Source: The Rhode Island Foundation

Role: Principal Investigator
Project: Uses advanced neuroimaging to examine the impact of type 2 diabetes on subcortical white matter and its relationship to cognition.
$10,000

HOSPITAL TEACHING ROLES

"Introduction to Clinical Neuroimaging I and II": Annual lectures to first year geriatric psychiatry residents.

Co-supervision of neuropsychology interns, Butler Hospital

Co-supervision of neuropsychology practicum students, Butler Hospital.

RESEARCH MENTORING

Served as co-mentor the following student projects:

Brown Undergraduates

Audrey Kwak, 2001-2 Psychology Honors Thesis
Project: Predictors of functional impairment in Alzheimer's disease

Leah Belsky, 2001-2 Biology
Project: When familial FTD is suspected: Ethical and clinical issues in genetic research

Sophie Desbiens, Summer 2002 Brain Science UTRA Fellow
Project: Development of an assay for notch-3 mutations

Suzanne Drodge, Summer 2002 MRI Research Facility UTRA Fellow
Project: Diffusion tensor imaging in CADASIL

Stan Pelosi, Summer 2002 PLME summer research assistantship
Project: Working memory in Alzheimer's disease (co-mentor with Dr. Malloy)

Jonathan Greer, 2003 PLME summer research assistantship
Project: A PCR-SSCP reliant assay for notch-3 mutations in CADASIL patients

Ryan Li, 2003-4 Neuroscience honors thesis
Project: MRI correlates of ambulation and motor functioning in Alzheimer's disease.

Thea Brennan-Krohn, 2004 Summer Training in Aging Research topics Mental Health- NIMH Award
Project: Diffusion tensor imaging and working memory in SIVD

Christopher Song, 2004 Summer Training in Aging Research topics Mental Health- NIMH Award
Project: Development of an assay for notch3 mutations

Kevin Patel 2005 Summer Brown MRI Research Facility UTRA Fellow
Project: Diffusion-tensor imaging in Alzheimer's disease.

Brown Medical Students

Shirine Nassery, PLME summer research assistantship 2001
Project: Relationship of subcortical microvascular changes in Alzheimer's disease to ApoE genotype and systolic hypertension

Risha Kopel, summer research project 2001
Project: Use of diffusion tensor MRI to differentiate normal pressure hydrocephalus from Alzheimer's disease

Ainsley MacLean, 2002 PLME summer research assistantship
Project: Phenotypic variation in a large family with CADASIL
Recipient of an Alzheimer's Association Travel Award to present her work at the 8th World Alzheimer's Disease Congress in Stockholm, 7/2002

Michael Joseph, 2005, Clinical Neuroscience Research Assistantship (summer)
Project: Relationship of hippocampal and whole brain volume to cognitive impairment in CADASIL.

Performed qualitative and quantitative ratings of hippocampal volume adjusted for intracranial volume.

Kevin Patel, 2005, Brown MRI Research Facility Fellowship (Fall semester)
Project: DTI Tractography Metrics: Incremental Validity and Correlation with Cognitive Function in Vascular White Matter Injury.
Assess the incremental value of new DTI tractography metrics over and above traditional volumetric measures of subcortical white matter hyperintensities for predicting cognitive function in patients with vascular cognitive impairment.

Wenjin Zhou, 2006. Doctoral Committee. Department of Computer Science. "Quantitative comparison of methods for interactively selecting 3D tracts-of-interest in Diffusion Imaging Datasets." David H. Laidlaw, PhD, major professor

CLINICAL MENTORING

Served as co-mentor for the following neuropsychology practicum students:

Erin Schlicting, University of Rhode Island

Elizabeth Schlicting, University of Rhode Island

REFERENCES

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Paul Malloy, Ph.D., Director of Neuropsychology, Butler Hospital, 345 Blackstone Blvd., Providence, RI 02906 (401) 455-6359 pmalloy@butler.org

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Hierarchical Selection Methods for DTI Fiber Bundles

PI: Matthew Loper
Co-PI: Ryan Boller
Consultant: Stephen Correia

Abstract

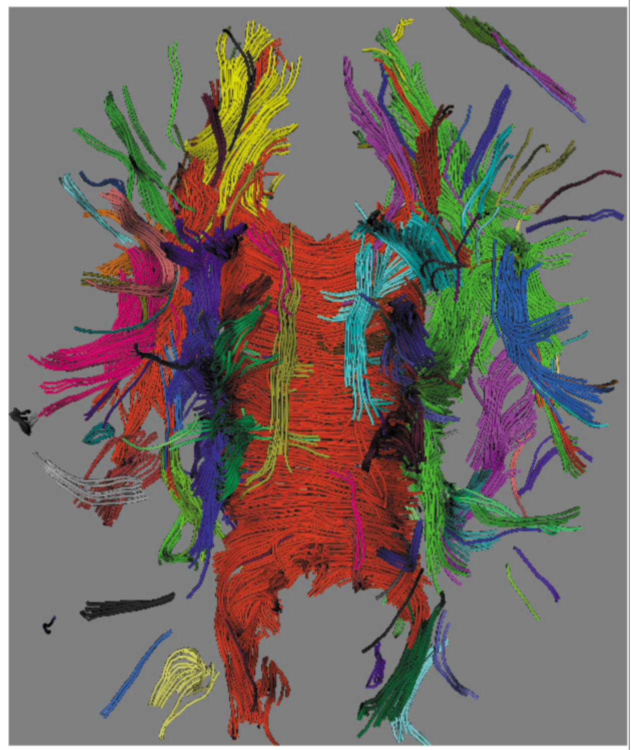
DTI-based tractography can be used for the recovery of brain connectivity information. We propose the development and evaluation of a new method for the interactive hierarchical selection of fiber bundles. This method will be used to investigate working memory impairments in patients suffering from a form of ischemic dementia.

1 Introduction

Much can be learned about the brain through the study of its physical pathways. The integrity and connectivity of these fiber tracts are indicators which vary between subjects. These indicators may lead to discoveries about healthy minds, and may also illuminate disorders that affect the brain. Many disorders have been studied in this light, including reading disabilities, multiple sclerosis, and schizophrenia [MORI02].

The predominant tool for the in vivo study of white matter tractography is diffusion tensor imaging (DTI), introduced by Basser et al [BASSER00]. The principle directions and extents of water diffusion in the brain are detectable with DTI. Because water diffusion in white matter is typically stronger in the direction of axonal tracts, DTI provides an indicator of the direction and stability of those tracts.

Fiber tracts tend to be organized into bundles. Fibers in a single bundle share approximate beginning and ending points, as well as overall shape; more importantly, such fibers may also share a common function. The integrity of particular fiber bundles can be compared between subjects. Such comparisons may soon uncover the function of certain bundles, and may eventually aid in the diagnosis and treatment of certain cognitive dysfunctions.


A visualization of one possible segmentation of DTI bundles in the brain (Moberts and Vilanova, 2005).

We are specifically interested in investigating memory problems for patients impaired by an inherited form of subcortical ischemic vascular dementia. This disorder is also known as cerebral autosomal dominant arteriopathy with subcortical infarctions and leukoencephalopathy (CADASIL). These patients have been shown to tend towards deficiencies in working memory [PETERS05]; working memory refers to short-term memory capacity and usage [BADDELEY92].

2 Problem Statement

In order to compare bundle integrity between patients, bundles must be found and segmented from the rest of the brain. Practically speaking, this requires a user to select three-dimensional regions of interest, given an onscreen depiction of diffusion tensor image data for a subject.

This is not a trivial problem. Fiber bundles assume irregular shapes and exhibit curvature, and do not always lend to the use of typical convex selection objects. Furthermore, bundles are often obscured by other bundles, which contributes to the difficulty of selection.

Ideally, a system might detect and segment any requested bundle automatically, given a DTI scan from any brain. However, the registration problem between brains is difficult ***(CITE???)***, and remains best performed by an expert.

Therefore, a more intelligent interactive selection process would be valuable in improving the speed and precision of segmentation. We wish to reduce the manual labor involved, without eliminating fine-grained control for the user. This requires finding a middle ground between complete automation and the tedium of manual selection.

3 Research Plan

Our research will be conducted in four phases. These phases will first be summarized, and then visited in more detail.

First, we will assemble a platform which allows a simple form of hierarchical selection. Next, we will extend functionality to include thickening, thinning, and length-based sub-selection. Next, our tool will be applied to the investigation of working memory problems in CADASIL patients. Lastly, we will conduct expert-driven comparison of our method with voxel-of-interest methods.

3.1 Simple Hierarchical Selection

As a starting point, we will be building on the BrainApp platform developed by Zhang et al. That application currently allows the visualization of Streamtubes [ZHANG00], which shows both hypothesized fiber tracts and the level of anisotropy (the latter is visualized with the use of the tube radius). Various thresholds may be used to reduce the initial density of Streamtubes. BrainApp also exposes a box-based selection method, in which boxes are delimited by the user, and fibers remain selected only if they pass through all of the created boxes.

The hierarchical selection process will proceed as follows. When the selection process is initiated, the entire brain will be coarsely clustered into a few colored fiber bundles, based on the methods of [ZHANG02], and visualized as Streamtubes. Upon cursor-based selection of one or more of these bundles, further cluster refinement will occur on those selected bundles. Non-selected bundles will take on some level of translucency based on the user's preference. Prominent bundle centerlines will be drawn along the median of each bundle, allowing selection of a bundle by clicking on the centerline.

3.2 Radius Adjustment and Length-Based Sub-selection

Given a selected fiber bundle, a user may wish to thicken or thin that bundle. In addition, a user may only want a particular subsection along the length of the bundle. We aim to allow the user to accomplish both tasks. Note that further investigation will be necessary to efficiently perform these operations, since they may involve changing the tree structure provided by Zhang's clustering mechanism.

3.3 Working Memory Investigation

This technique will be used to help segment white matter fiber bundles that have complex trajectories; such trajectories curve in more than one plane simultaneously, and are therefore difficult to segment using traditional voxel-of-interest placement (i.e., boxes).

There are two pathways of interest for this project:

1. The fronto-parietal segment of the superior longitudinal fasciculus, a large fiber bundle that courses posteriorly from the anterior temporal lobe and then curves superiorly and medially (the arcuate segment) before coursing anteriorly to the dorsolateral prefrontal cortex [CARPENTER91]. The fronto-parietal segment is important in working memory abilities [KARLSGODT07].
2. The uncinate fasciculus, which courses posteriorly and medially from the anterior temporal lobe to the orbitofrontal region [CARPENTER91] and is involved in working memory and emotional memory [MTL05]. The computational segmentation tools will be used to assess the

structural intregrity of these fibers in patients with an inherited form of subcortical ischemic vascular dementia (i.e., cerebral autosomal dominant arteriopathy with subcortical infarctions and leukoencephalopathy (CADASIL)) [SLW05] which is characterized by working memory impairments [PETERS05].

3.4 Expert-driven Comparison

We will compare our method with a voxel-of-interest (box-based) selection method. Specifically, experts will be given the task of selecting the fronto-parietal segment of the superior longitudinal fasciculus and the uncinate fasciculus. This task will be performed on an application developed as part of this project. Experts (including Stephen Correia, and potentially his colleagues) will be timed in their completion of these tasks, and qualitative feedback will be acquired.

4 Scientific Contribution

In the short term, research on the working memory of CADASIL patients will further the understanding of deficiencies for those patients. The progress of this research would ideally be accelerated by the mentioned hierarchical interactive selection techniques.

If this hierarchical mode of interaction proves successful, the general problem of bundle comparisons will also benefit from these improved selection techniques. Such comparisons benefit research in numerous areas, including (but not limited to) reading disability, multiple sclerosis, schizophrenia, and HIV. Our method of interaction has the potential to accelerate this research.

If this mode of interaction does not prove successful, it may either pave the way for successful variants of the proposed technique, or it may illuminate practical shortcomings that guide future researchers to more successful methods.

5 Related Work

Our work requires an appropriate clustering algorithm in order to create fiber bundles. We use the technique of [ZHANG02], which successively merges clusters into a tree hierarchy. An evaluation of competing clustering methods for DT imaging can be found in [MOBERTS05].

A DTI selection method was proposed in [SHERBONDY05]. In that work, boxes were used to select fibers, and viewed fibers could be interactively changed by altering these boxes or by changing query parameters (such as fiber length, or average curvature). Although this method allows interactive selection, it does not address the difficulty of using a polygonal object to select an irregular, often smooth, and potentially obscured fiber bundle.

In a more recent work on DTI imaging selection methods [BLAAS05], fast methods were developed for selection of bundles using multiple polyhedral convex objects. In our view, that work has the same drawbacks of [SHERBONDY05].

6 Timeline

Week 1:	Familiarize with BrainApp architecture
Week 2:	Implement basic bundle selection
Week 3:	Make selection hierarchical
Week 4:	Add length and radius adjustments
Week 5:	Investigate working memory, and conduct expert method comparisons
Week 6:	Write up results

(note: this bibliography was generated by openoffice, and is ugly as sin. i will replace it.)

Bibliography

MORI02: Susmi Mori and Peter C. M. van Zijl, Fiber tracking: principles and strategies - a technical review, 2002
BASSER00: Peter J. Basser and Sinisa Pajevic and Carlo Pierpaoli and Jeffrey Duda and Akram Aldroubi, In Vivo Fiber Tractography Using {DT-MRI} Data, 2000
PETERS05: Nils Peters and Christian Opherk and Adrian Danek and Clive Ballard and Jurgen Herzog and Martin Dichgans, The pattern of cognitive performance in CADASIL, 2005
BADDELEY92: A. Baddeley, Working Memory, 1992
ZHANG00: , Visualizing diffusion tensor mr image using streamtubes and streamsurfaces,
ZHANG02: Song Zhang and David H. Laidlaw, Hierarchical Clustering of Streamtubes, 2002
CARPENTER91: , Core Text of Neuroanatomy, 1991
KARLSGODT07: K. H. Karlsgodt, Diffusion Tensor Imaging of the Superior Longitudinal Fasciculus,
MTL05: S. A. Mitelman, Cortical intercorrelations of frontal area volumes in schizophrenia, 2005
SLW05: S. Salloway and S. Desbiens, CADASIL and Other Genetic Causes of Stroke and Vascular Dementia, 2004
MOBERTS05: B. Moberts and A. Vilanova and J.J. van Wijk, Evaluation of fiber clustering methods for diffusion tensor imaging, 2005
SHERBONDY05: Anthony Sherbondy and David Akers and Rachel Mackenzie and Robert Dougherty and Brian Wandell, Exploring Connectivity of the Brain's White Matter with Dynamic Queries, 2005
BLAAS05: Jorik Blaas and Charl P. Botha and Bart Peters and Frans Vos and Frits H. Post, Fast and Reproducible Fiber Bundle Selection in DTI Visualization, 2005

MATTHEW M. LOPER
(note: this resume is over 2 years old, and should be updated)
34 E George St.
Providence, RI 02906
email: matt at cs.brown.edu

OBJECTIVE: To work on problems relating to computer graphics, vision, and video.

POSTERS / WORKSHOPS:

June 2005 O. Jenkins, G. González, and M. Loper. Learning dynamical motion vocabularies for kinematic tracking and activity recognition. In *CVPR 2006 Workshop on Vision for Human-Computer Interaction*, New York, NY, USA, Jun 2006.

July 2005 S. Apte, M. Loper, P. McNally, "Enviromosaics."*Proceedings of the ACM SIGGRAPH Conference, 2005*.

PUBLICATIONS:

August 2004 W. Matusik, M. Loper, and H. Pfister, "Progressively-Refined Reflectance Functions from Natural Illumination."*Proceedings of Eurographics Symposium on Rendering 2004*. (Patent filed June 18, 2004.)

EDUCATION:

September 2004
Brown University PhD Program
Coursework: Computer Vision, Interactive Computer Graphics, Robotics, Smart Camera Networks, Forensic Vision, Video Processing, Computational Biology

September 1997-2003
Harvard Extension School: GPA 3.9
Coursework: Image-Based Modeling and Rendering, Geographic Information Science, Advanced Computer Graphics, COM Programming and ActiveX

EXPERIENCE:

Spring 2006
Brown University
Teaching Fellow: Assisted in teaching "Interactive Computer Graphics" with John Hughes (Spike). Created and graded homeworks. Held office hours, and answered questions on the class mailing list.

November 2003
to January 2004
Mitsubishi Electric Research Labs
Intern: Worked with W. Matusik and H. Pfister on the conception and development of a system for relighting objects in natural scenes.
Cambridge, MA

September 2002
to May 2004
Harvard Extension School
Teaching Fellow: Assisted in teaching "Introduction to Computer Graphics" and "Advanced Topics in Computer Graphics" with Hanspeter Pfister. Created and graded homeworks. Held office hours, and answered questions on the class mailing list.

December 1999
to July 2000
Ximian, Inc.
Evolution Project Manager: Managed fourteen programmers in the development of a complete groupware solution for Linux. Adapted Bugzilla to distributed project management, collected and generated status reports for the team, and interviewed potential Evolution team members.

Ryan A. Boller
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PRESENT POSITION:
Computer Scientist, Advanced Data Management and Analysis Branch
Information Systems Division, NASA / Goddard Space Flight Center

EDUCATION:
B.S., Computer Science, Pennsylvania State University, 2000
M.S., Computer Science, Brown University, 2008 (expected graduation)

RESEARCH INTERESTS:
Scientific visualization, human-computer interaction, robotics, and remote sensing.

EXPERIENCE:

2001-present	Computer Scientist, NASA / Goddard Space Flight Center
2000	Intern, VideoMining, Inc.
1999	Intern, The Robotics Institute / Carnegie Mellon University
1998	Co-op student, Intel Corporation / Microcomputer Research Laboratories

HONORS and AWARDS:

2006	Science Magazine/National Science Foundation "2006 Visualization Challenge" competition - Honorable Mention (team)
2002-6	GSFC Performance Awards – Exceptional Service
2003	NASA and GSFC Group Achievement Awards - Polar, Wind, and Geotail Ground Systems Re-engineering Team

PUBLICATIONS:

1. Collado-Vega, Y.M., Kessel, R.L., Shao, X., Boller, R.A. "MHD flow visualization of magnetopause boundary region vortices observed during high speed streams", *Journal of Geophysical Research, Vol. 112,* A06213, 2007.
2. Bradski, Gary R., and Boller, Ryan A. (1998). Intel Corporation. Synthesizing Computer Input Events. U.S. Patent 6,396,476.
3. Bradski, Gary R., Holler, Mark A., and Boller, Ryan A. (1998). Intel Corporation. Computer Vision Control Variable Transformation. U.S. Patent 6,538,649.

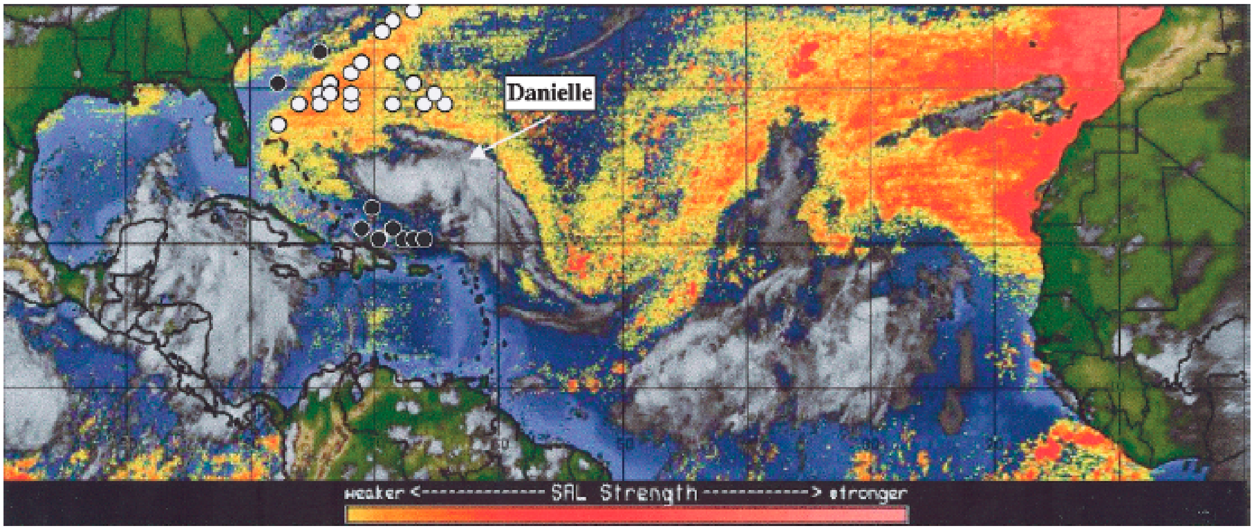
American Geophysical Union conference talks (abstracts at http://adsabs.harvard.edu/):

1. "MHD Flow Visualization of Magnetopause and Polar Cusps Vortices", 2006
2. "Insights into Planar Magnetic Solar Wind Structures Using New Visualization Methods", 2004
3. "Vector and Scalar Field Visualization Techniques for Multispacecraft Space Physics Missions", 2003
4. "Building a Virtual Space Physics Observatory for Easy Access to and Novel Visualization of Distributed Data", 2003
5. "Three-Dimensional Visualization of Space Physics Data", 2002

LETTER OF SUPPORT

Note: I have received spoken support from Dr. Correia, but I have not yet received a formal email of support. This will be integrated into the proposal shortly.

Visualizing and Identifying Correlations Between the Saharan Air Layer and Dust Storms During Periods of Active Tropical Cyclogenesis



Saharan Air Layer (orange/red) and Hurricane Danielle [Dunion and Velden, 2004]

ABSTRACT

The effects of Saharan dust and potentially related hot, dry air masses on developing hurricanes are poorly understood. Some meteorological studies show that these conditions favor increased hurricane development, while other studies show that development is suppressed. While there are supported cases for each scenario, identifying the mechanisms at work have proven elusive, thereby making impossible to create accurate forecasts during this early stage of hurricane development.

Our overall goal is to gain better insight into the interaction between hurricanes and this dusty layer of Saharan air, enabling better long-range forecasts of a hurricane's intensity and track. Before we can do this, certain basic questions must be addressed. For this BUSPFA solicitation, we propose to use a global climate model (GCM) to identify correlations between dust distribution and relative humidity, showing the relative motions of Saharan air layer (SAL) and dust in 3-D. From this, we can determine if the dust field is a good proxy for the SAL: do they move together or are they independent? If they move together, this will allow us to use real-world measurements from satellites to identify the extent of the SAL since dust is much easier to detect than the specific characteristics of an air mass.

Co-PI:	Ryan Boller	Student	Brown University
Co-PI:	Matthew Loper	Student	Brown University
Collaborator:	Scott Braun	Research Meteorologist	NASA / GSFC
Consultant:	Arlindo da Silva	Research Meteorologist	NASA / GSFC

"Hitching our research to someone else's driving problems, and solving those problems on the owners' terms, leads us to richer computer science research."

- Fred Brooks, Professor of Computer Science,
University of North Carolina, Chapel Hill

Background

We propose an interdisciplinary project to advance meteorological research through new visualization tools that will help to identify and quantify contributing factors of hurricane development during early stages. These tools will be developed in close collaboration with research meteorologists working on this problem. They will provide scientific goals and guidance, while computer scientists will provide the innovative tools necessary to enable new insights into this poorly understood meteorological process.

An ultimate goal of this work is to enable better long-range forecasts of a hurricane's intensity and track. While this is a somewhat lofty proposition, we think we can chip away at it through several incremental steps, each with an associated meteorological question and visualization solution. This proposal will address one of these problem sets. Taken as a whole, these sets will form the basis for Boller's master's thesis project.

This proposal will focus on the interactions between hurricanes and a hot, dry air mass that originates over western Africa called the Saharan air layer (SAL), as shown in Figure 1. First detailed by Carlson and Prospero in 1972, it is usually dust-laden and travels long distances to the west, crossing the Atlantic Ocean in 5-6 days. Along the way, the continuous fallout of particulate matter can cause a dense, low-level haze near the surface of the Atlantic and Caribbean oceans.

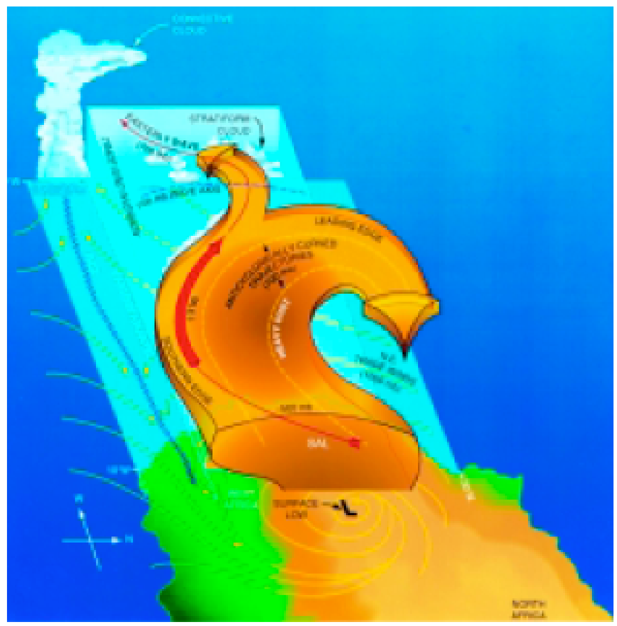


Figure 1: Schematic of the Saharan Air Layer [Karyampudi et al 1999] (need better resolution)

As one might imagine, large amounts of dust and the presence of a strongly defined air mass are likely to affect the weather patterns with which it shares space. Depending on the quantities and strengths involved, the SAL has been documented to affect hurricane development, otherwise known as tropical cyclogenesis (TC). In a 2004 study by Dunion and Velden, satellite imagery revealed that the SAL might play a major role in suppressing TC activity in the North Atlantic. Specifically, an enhanced low-level temperature inversion, an increase in temperature with altitude, forms due to the absorption of solar radiation by the suspended dust. This limits vertical motion through the SAL, thereby limiting the convection needed to form and sustain a hurricane. They also propose that the SAL's dry air intrudes into the moist TC circulation, along with introducing vertical wind shear that causes the nascent hurricane to tear apart.

On the other hand, another study attributed increased hurricane activity to the SAL [Karyampudi and Pierce 2002]. They found that, under certain conditions, the SAL imposed baroclinity, ordered layering, along the leading and southern edges of the SAL front. This enables hurricanes to remain "well stacked," keeping its warm core intact. Karyampudi and Pierce also state that, under other conditions, the SAL can produce convective conditions favorable to hurricane development.

From these and other studies, correlations have been shown between the SAL and TC activity, but they are still not entirely understood. Satellite observations have formed the basis of most of these studies, but as with many types of remotely sensed data, it can be incomplete and limited in scope. For example, [Dunion 2004] states, "Because of the SAL's limited vertical extent, its dry air can be difficult to quantify using the moisture channels on the GOES and Meteosat second-generation (MSG) satellites. The most effective way to study the SAL's low humidity is by first identifying it with the GOES SAL-tracking imagery and then directing aircraft to make in situ measurements of its thermodynamic structure."

Scientific Approach

Traditionally, it is difficult to perform a comprehensive analysis of several SAL/TC interactions since it is not feasible to request frequent aircraft measurements due to budgetary and logistical constraints. Fortunately, recent advances in global circulation/climate models (GCMs) have increased enough in resolution to simulate hurricanes and dust transport. In addition, they can provide complete, comprehensive measurements of the entire atmosphere in 3-D, overcoming the satellite-based limitations of having data gaps and being restricted to 2-D. Also, GCMs regularly assimilate actual satellite data to ensure that the model does not drastically diverge from reality.

Therefore we propose to use output from the GEOS-5 global circulation model[1] to track dust, wind, humidity, and temperature over time and 3-D space to determine if the dust field is a good proxy for the SAL. If that proves to be true, it will allow us to use satellite observations to identify the extent of the SAL since dust is much easier to detect than the specific characteristics of an air mass.

This, however, is not the first attempt of using a GCM to show correlations between the SAL and dust outbreaks. A model-simulated climatology by Jones et al. [2004] indicated that the westward transport of dust is modulated by African Easterly Waves (AEWs), which propagate from the west coast of North Africa across the tropical Atlantic Ocean. (RB: reword as necessary).

These results will be valuable to our proposed work. It will provide a scientific and technical basis for validation of our initial results. However, while their work focused on the effects of dust on AEWs, our work will focus on a correlation and morphological comparison between dust and the more sporadic, regional SAL. It will enable future analysis of dust and SAL impact on tropical cyclogenesis, becoming the basis for Boller's thesis work in the form of a restricted-scope meteorological problem-solving environment.

Visualization Approach

Key to all of this is improved visualization tools and techniques for a more comprehensive understanding of the processes at work. Surprisingly, even though they are inherently 3-D spatial problems, all of the studies reviewed in the preparation of this proposal relied almost entirely on 2-D plots, such as the one shown on the title page by Dunion and Velden. In the year 2000, Vis5D creator Bill Hibbard summarized the state of meteorological visualization as follows:

> "While 3D visualizations of weather and other environmental simulations have been around for many years, 3D graphics are only slowly being adopted by working meteorologists. Within the last few years, 3D visualization systems have been installed in

[1] http://gmao.gsfc.nasa.gov/highlights/tc4mission/tc4mission.php

many government agencies responsible for developing weather, ocean and air pollution models. While the scientists who develop models at those agencies do use these 3D systems, they still primarily rely on 2D graphics. The meteorologists responsible for making public forecasts based on weather model output, rarely make use of 3D visualization. There is a good reason for this: like doctors and airplane pilots, forecasters' mistakes kill people and they are rightfully skeptical of new technology."[2]

While Hibbard's logic for meteorologists' primary usage of 2-D graphics is reasonable, it still leaves hope that 3-D graphics will be adopted once it is a "proven" technology. While it is out of the scope of this proposal to prove the utility of 3-D graphics over 2-D, it will strive to make its 3-D results quantifiable and intuitive, attributes that are perhaps lacking in many existing 3-D meteorological visualizations.

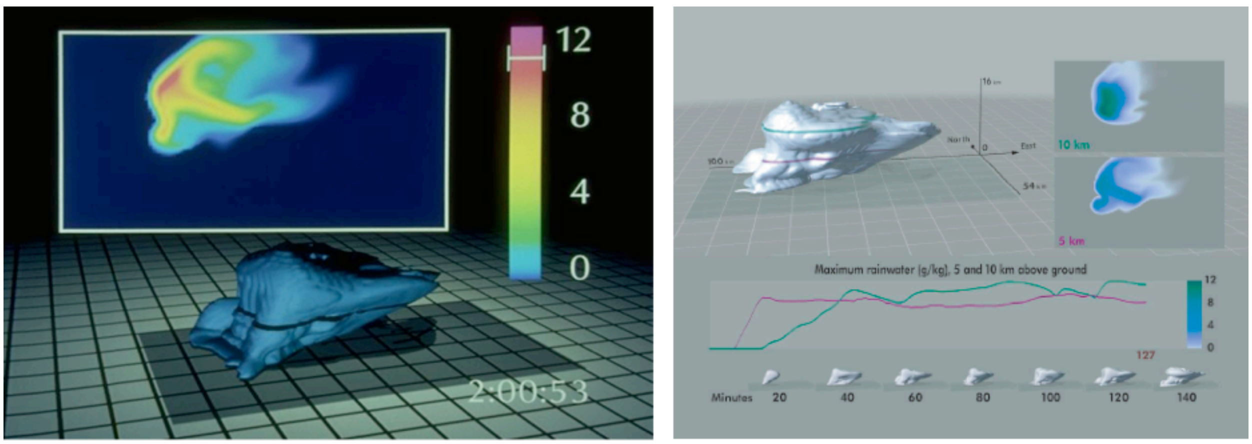


Figure 2: Wilhelmson's classic thunderstorm visualization (left) next to its revision (right)

As a positive example of these attributes, we will use Wilhelmson et al's classic thunderstorm visualization from 1990, along with the subsequent critiques [Baker and Bushell 1995, Tufte 1997] as a basis for our initial design (see Figure 2). To ensure color mappings are consistent with what meteorologists expect, we will set the default color palettes as described in [Hoffman et al 1993].

The main computational task will be to identify and track the dust plume and SAL over space and time. Both "objects" should be relatively distinctive in their respective meteorological properties. I.e., the SAL should be much drier and hotter than the air mass surrounding it. Standard computer vision tracking techniques, such as optical flow, are expected to work without much hassle since the data has a very high signal-to-noise ratio. The expected difficulty will likely lay in comparing the two amorphous volumes in a meaningful way. (Matt: please provide your speculative algorithms here).

Likewise, the main visualization task will be to depict the relative and absolute motion of each volume in a way that clearly identifies correlations between these dynamic 3-D quantities. On one level, this could be considered to be a simple comparison between the extents of two volumes. However, it will also be important to show what role specific characteristics of the SAL (wind, humidity, etc) play in the progression of a dust outbreak. Volume rendering techniques for illustrating meteorological fronts described in [Kniss et al 2002] should provide a good starting point for showing the interaction between two air masses. However, the challenge of comparing two overlapping air masses is not addressed, nor is the challenge of comparing their tracks and morphology over time. This should provide a rich area for innovation in meteorological visualization design.

[2] http://old.siggraph.org/publications/newsletter/v34n1/contributions/guested.html

Finally, after performing a comprehensive review of relevant existing visualization tools and libraries, we decided that NCAR/Unidata's open-source Integrated Data Viewer (IDV)[3], built atop the popular meteorology visualization library of Vis5D, was the best choice as a starting point. It is already set up to handle common meteorology coordinate systems and data formats, hopefully eliminating some of the requisite groundwork for this type of visualization project.

Research Plan

Week	Dates	Milestone	Description
1	11/01-11/07	- Project goals agreed upon with BUSPFA and team - IDV software architecture installed - Sketches of expected interface/visualizations made	- Re-scope goals with BUSPFA based on funding, if necessary - Discuss sketches with end users
2	11/08-11/14	- GEOS-5 HDF-EOS data import module completed - Basic data display possible	
3	11/15-11/21	- Loper: computer vision segmentation algorithms applied - Boller: volumetric rendering algorithm(s) applied	
4	11/22-11/28	- Loper: CV tracking algorithms applied - Boller: method developed to show differences between shape and position/track of volumes	
5	11/29-12/05	- Loper: algorithm to compare 3-D amorphous volumes completed - Boller: "internal" SAL quantities visualized; i.e., temp & humidity - First draft of abstract and presentation completed	- Discuss abstract/presentation with writing fellow
6	12/06-12/13	- Loose ends tied - Presentation completed and delivered	

Facilities

While the amount of specialized hardware and software available at Brown University and Goddard Space Flight Center is extensive, the target platform of the proposed software is the scientist's desktop. The goal is to allow the end user to spend as much time as desired with the tool, as well as to provide the capability for easy distribution of the software to any interested parties. Because of these

[3] http://www.unidata.ucar.edu/software/idv/

constraints, the software should take advantage of modern computer architectures and graphics capabilities to provide interactive responses to the user's requests.

Experience and Partnering

We believe that we have assembled a team that is well suited to address the content and scope of this project from our past experiences and current interests. Braun is a recognized expert in using computer modeling to recreate the components of hurricanes, such as winds, rainfall, and in-cloud heating. His current research directly aligns with this project, focusing on the processes that impact the formation, intensification, movement, structure, and precipitation organization of hurricanes[4] (RB: reword as necessary).

Boller has been involved with interdisciplinary scientific visualization projects at NASA for the past five years. This work has primarily focused on creating specialized tools to better understand Earth and space science data from NASA's orbiting fleet of satellites. Additionally, he has worked with supercomputer-based simulations of the interactions between solar storms and the Earth's magnetic field. These experiences should provide a solid basis when using large global climate simulations in this project.

Loper has extensive experience in computer vision, image processing, and computer graphics. This should be invaluable when developing algorithms to segment and track air masses and dust plumes autonomously, as well as in taking advantage of the latest computer graphics algorithms.

Additionally, Boller and Loper have a good track record of collaboration during projects in Brown University's "Building Intelligent Robotics" course during the fall 2006 semester. Braun and Boller have built a working relationship during the summer of 2007 at NASA. Braun has been very supportive during the project formulation phase, providing substantial scientific background to the participating non-meteorologists.

[4] http://www.nasa.gov/mission_pages/hurricanes/bios/braun_bio.html

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Wong, S., P. R. Colarco, and A. E. Dessler (2006), Principal component analysis of the evolution of the Saharan air layer and dust transport: Comparisons between a model simulation and MODIS and AIRS retrievals, *J. Geophys. Res.*, 111.

Ryan A. Boller
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PRESENT POSITION:
Computer Scientist, Advanced Data Management and Analysis Branch
Information Systems Division, NASA / Goddard Space Flight Center

EDUCATION:
B.S., Computer Science, Pennsylvania State University, 2000
M.S., Computer Science, Brown University, 2008 (expected graduation)

RESEARCH INTERESTS:
Scientific visualization, human-computer interaction, robotics, and remote sensing.

EXPERIENCE:

2001-present	*Computer Scientist, NASA / Goddard Space Flight Center* Scientifically visualized Earth & space science data from satellites; Lead developer of ViSBARD, the Visual System for Browsing, Analysis, and Retrieval of Data, a space physics data analysis toolkit
2000	*Intern, VideoMining, Inc.* Developed multimodal interfaces and computer vision applications
1999	*Intern, The Robotics Institute / Carnegie Mellon University:* Developed computer vision libraries for 3-D geometry processing
1998	*Co-op student, Intel Corporation / Microcomputer Research Laboratories* Performed HCI research/development with computer vision algorithms

HONORS and AWARDS:

2006	Science Magazine/National Science Foundation "2006 Visualization Challenge" competition - Honorable Mention (team)
2002-6	GSFC Performance Awards – Exceptional Service
2003	NASA and GSFC Group Achievement Awards - Polar, Wind, and Geotail Ground Systems Re-engineering Team

PUBLICATIONS:

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2. Bradski, Gary R., and Boller, Ryan A. (1998). Intel Corporation. Synthesizing Computer Input Events. U.S. Patent 6,396,476.
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2. "Insights into Planar Magnetic Solar Wind Structures Using New Visualization Methods", 2004
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4. "Building a Virtual Space Physics Observatory for Easy Access to and Novel Visualization of Distributed Data", 2003
5. "Three-Dimensional Visualization of Space Physics Data", 2002

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July 2005 S. Apte, M. Loper, P. McNally, "Enviromosaics."*Proceedings of the ACM SIGGRAPH Conference, 2005*.

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Spring 2006
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December 1999
to July 2000
Ximian, Inc.
Evolution Project Manager: Managed fourteen programmers in the development of a complete groupware solution for Linux. Adapted Bugzilla to distributed project management, collected and generated status reports for the team, and interviewed potential Evolution team members.

From: braun@agnes.gsfc.nasa.gov
Subject: **Re: Hurricane visualization research**
Date: April 16, 2007 4:11:40 PM EDT
To: Ryan.A.Boller@nasa.gov

Hi Ryan,

I'd be glad to work with you on this or provide some data that you could use. How about meeting up some time soon to discuss possibilities? My schedule this week is as follows:

Tuesday: free except 3-4 pm
Wednesday: free except 11:30-2:30pm
Thursday: free except 3:30-4:30pm
Friday: open

We can also look into next week if that is better.

Scott

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Interactive Particle Visualization in 3D Time Varying Vector Fields

Scott Daniel
Computer Science
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Abstract

Electron particle accelerators are expanding scientific knowledge at a tremendous rate. In order to evaluate and test designs for new types of particle accelerators scientists need ways to visualize particle accelerator simulations. In this proposal we present a tool for interactively visualizing particle accelerator simulations in 3D.

Introduction

Linear accelerators are devices used in synchrotron particle accelerators to accelerate electrons. By inducing powerful electric fields the linear accelerators are able to accelerate electrons to nearly the speed of light as they pass through and into the storage ring. As electrons move at such high speeds they emit a continuous spectrum of energy which produces various kinds of waves such as infrared, ultraviolet, etc. Scientists are then able to select the wavelength they desire to perform various experiments.

As a result particle accelerators have been contributing to scientific knowledge in multiple disciplines at a staggering rate. In particular, particle accelerators are used to advance research in physics and scientific understanding of matter. They have also been used to study areas including fusion and energy.

In order to better understand the behavior of particles and electric fields inside a linear accelerator scientists have developed simulations to model the process of accelerating particles. But these simulations often output large data sets. Inspecting the data output from a simulation would be too difficult to extract useful information about the simulation. In addition, it would not convey much information about the behavior of the particles or the field. In order to extract meaningful information scientists must have some visualization that allows them to visually observe how the particles and electric field are behaving.

Related Work

Advanced research in visualizing linear accelerator simulations for large data sets has already been started by the visualization group at UC Davis. A paper they presented in 2004 addresses the two issues of rendering large amounts of particle data and also vector field details [2].

In their paper they present a hybrid approach for rendering particles as both points and volumes depending on a user adjusted transfer function. This hybrid approach is intended to maintain interactive frame rates during visualization and to cut down on memory requirements for storing the particles. Regions of lower particle density are considered more interesting and thus are rendered as points whereas particles in denser regions are rendered as textured volumes. A similar approach will likely be adapted for this project.

The second contribution of the paper is the new representation of the vector field using self-orienting streamline meshes. Although a novel approach this method suffers from the sheer use of mesh representations for the vector field. This paper does not address integrating both approaches for a simultaneous visualization of both particles and electric field. As a result it is our guess that integrating both approaches will not deliver desirable results.

Previous attempts have already been made to visualize linear accelerator simulations. Notably, a tool called VTK was developed to address multiple visualization problems in different disciplines [1]. Unlike the research done at UC Davis the visualizations presented by VTK allow for a complete visualization of particles, electric field, and mesh shape simultaneously.

VTK is currently used by my collaborator to visualize his simulation data but it has multiple shortcomings in the way it presents information to the user. For instance, the arrow based vector visualization method in conjunction with the point based particle representation does not provide a very useful representation of the simulation to the user. Most of the useful information about where particles are and where they are going is occluded by presentation of the vector field arrows imposed over the particles. In addition this tool is intended for use on commodity workstations and thus constrains the user to the interface provided by their environment. To contrast, our approach will allow a more fluent interaction between the user and the simulation visualization through novel use of a 3D environment.

Research Goals

The primary goal for this project is to develop a tool that allows the user to interactively visualize the particles, electric field, and linear accelerator shape of a linear accelerator simulation in 3D. The purpose of using a 3D environment over traditional workstation environments is that it inherently solves issues related to depth and spatial perception when rendering particles and vector fields. Using a 3D environment will allow the user to easily view the simulation from multiple vantage points and also to allow the user to zoom in on regions of interest. As our interactive 3D environment we will be using the Power Wall available to the Brown University Center for Computation and Visualization. The Power Wall provides a graphics API for programming visualization tools along with stereo glasses and an interactive interface to allow the user to visualize the data in 3D space.

In order to visualize the particles, electric field and linear accelerator shape simultaneously we will combine various approaches with the hypothesis that they will interact well together and a convey the greatest amount of information to the user. The UC Davis hybrid approach described earlier will be used to visualize the particles. The choice for this method lies in the fact that it supports two goals, first for rendering particles that are of most interest and second it will reduce memory requirements and allow our tool to maintain interactive frame rates.

The approach used to visualize the electric field is driven by the need to simultaneously visualize all the parts of a linear accelerator simulation. Previous visualization techniques for visualizing vector fields have included the use of stream polygons, illuminated streamlines, and flow volumes [3, 4, 5]. Unlike these methods for visualizing 3D vector fields we chose to use streamlets to animate the flow path of the vector field. The motivating factor behind streamlets was that they are small and individually do not take up much space in the visualization.

Significance

This multidisciplinary effort aims at developing a new way to visualize linear accelerator simulations in order to gain a better understanding of how linear accelerator design affects the behavior of electron particles and the electric field. The contributions to visualization are methods of applying techniques for visualizing particles and vector fields to novel hardware such as the Power Wall. The contribution to applied mathematics is that this tool will provide a method for validating simulation results. As a result applied mathematicians will be able to develop and improve their computational models. In addition, the tool will allow scientists to analyze new configurations for linear accelerations for evaluation.

Facilities

The Power Wall located inside the Center for Computing and Visualization (CCV) at Brown University will be used to visualize the linear accelerator simulations. The Power Wall is well suited for this particular project because it allows the user to perceive that their data is projected into 3D space with the help of stereoscopic glasses. In addition the users will have tools available that allow them to manipulate the visualization to obtain different vantage points which provides for a more interactive and immersive experience.

Work Plan

Week 1
Become familiar with the Power Wall facilities and learn how to program it with the API.

Week 2
Begin implementing the interface and visualization software that will render the simulation data. In particular develop the parser to read in the simulation data and test particle and vector field visualization with small data sets using point particle and streamlet vector field representations.

Week 3
Implement the basic UI tools for loading and visualizing particle accelerator simulations. Test basic functionality such as rotating, panning, and zooming the visualization while time stepping through the simulation data as well as during a full animated run through of the simulation.

Week 4
Implement the hybrid particle visualization as described in [2]. Begin testing particle visualization on larger data sets. Add UI tools that allow the user to set the transfer function for the hybrid visualization.

Week 5
Add linear accelerator shape representation to the visualization tool. Augment the UI to allow the user to select a threshold for highlighting parts of the hull walls that are hit most frequently by particles.

Week 6
Run visualization tool against data sets with known results to evaluate the effectiveness of the visualization tool. Write the final abstract.

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The Relationship Between Cell Topography and Neural Growth: A Computational Approach

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Abstract

To induce in-vivo nerve regeneration, researchers are currently exploring and measuring the effects of various factors that contribute to neural growth. In this proposal, we introduce three dimensional quantitative metrics to examine the relationship between neural growth and one such factor: cellular topography. The 3D techniques proposed will be quantitatively compared to the state-of-the-art 2D image analysis techniques and evaluated by expert users.

1 Introduction

We propose a collaborative research effort between the departments of computer science and bio-medicine at Brown University, aimed at the biological challenge of enhancing nerve regeneration in-vivo. In an attempt to facilitate nerve regeneration, biologists at Brown have engineered polymers capable of replicating cellular topography with nanoscale precision. Once these cellular footprints are formed and cell cultures are introduced, questions arise as to how effectively the new cells grow along the given topography.

Attempts to quantify the effectiveness of such techniques have been made in two dimensions using image analysis with moderate success [1]. As research progresses and becomes more complex, however, it is clear that these 2D techniques will fail. We propose volumetric techniques to measure and compare the directionality of neural growth with respect to an imposed topography, as well as the quality of such neural growth. We will compare our results directly to the state-of-the-art 2D methods and collect expert feedback on our tools.

2 Scientific Background

After injury or degeneration, nerve cells must navigate complex environments in order to reconnect to their proper targets or bridge dysfunctional areas. During this process, regenerating cells integrate a variety of soluble, substrate-bound, and topographical cues, the sum of which can foster or prevent regeneration. Central nervous system environments discourage nerve regeneration on a variety of chemical and mechanical levels, which provides the motivation to develop methods that will allow such regeneration. The working hypothesis behind this research is that cellular topography can dominate over other environmental cues and that aligned cell-shaped topography directs and enhances neural growth during development and after injury [2],[1].

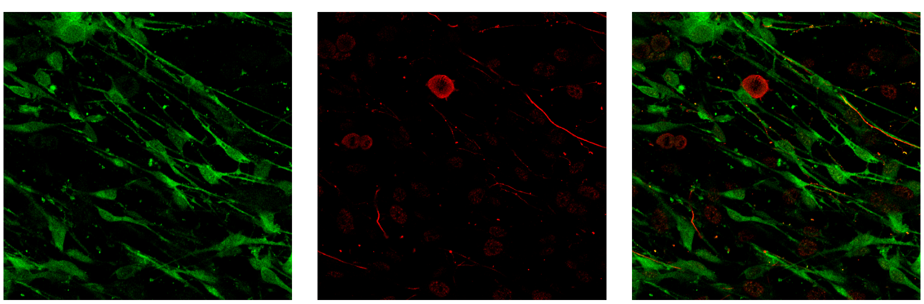

Figure 1: In the images above, the green channel is used to display Schwann cells and the red channel is used to display neurons. All three images are from the same representative slice of a confocal microscopy image stack. Not visible in the images is the polymer the cells are grown on, which features the cell topography of living Schwann cells.

3 Related Work

To date, quantitative analysis of confocal microscopy image stacks has been limited to two-dimensional image analysis. Using software tools such as ImageJ, Matlab's Imaging Toolbox, and CellProfiler, biologists are well equipped to answer questions about planar images, as seen in [6], [5], [8], [3], [10]. Cell and nuclei counting, proximity measures and pattern recognition are features these packages are capable of within a 2D setting. With respect to quantifying the orientation of cellular growth, simple two-dimensional methods have been introduced, though their margin for error is ±10 degrees. These methods stand as the best attempt to quantify the effect of cellular topography on neural growth, and they were implemented using custom Matlab code here at Brown University [1].

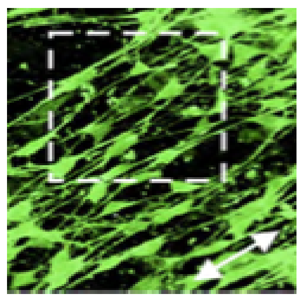

Figure 2: Bruder's method for quantifying alignment in 2D.

Very limited work has been done to quantify confocal microscopy image stacks volumetrically. Several groups have worked on volume rendering techniques to visualize the data in 3D as seen in [4], but little else has been done from a computational standpoint in three dimensions.

4 Proposed Methods

While it is feasible to apply two dimensional image analysis techniques to volumetric data taken from a relatively flat surface, such methods clearly fail in analyzing volumes taken from more complex 3D structures. Since it is critical to quantify neural growth on the types of complex structures encountered in-vivo, the progression of this research hinges on the development of three-dimensional methods for cellular analysis.

4.1 Visual Environment

The proposed application will make use of several tools and software libraries built at Brown University. Volume rendering will be facilitated with use of the Virvo library used in [9], and the main application will be built on top of the

G3D and VRG3D APIs, which will allow for stereo rendering in an immersive environment such as the CAVE or a fishtank desktop setup.

4.2 3D Metrics

In order to quantify the success of neural growth, we propose techniques to analyze two neural properties in three dimensions: directionality and health of cells. To measure three dimensional directionality in such a way that will be generalizable enough to apply to cells grown on complex 3D surfaces, we propose an ellipsoid fitting method to capture as much of the cellular alignment as possible. Such techniques have previously been applied to DTI data with success [7].

To effectively measure "health" of cells, we propose metrics to describe neural density, as well as neural proximity to other cell types. It is known that unhealthy, or dying neurons will often isolate themselves from other cell types, which makes this a meaningful metric. Again, we believe these measurements using 3D volumetric methods will be a significant advance over 2D methods.

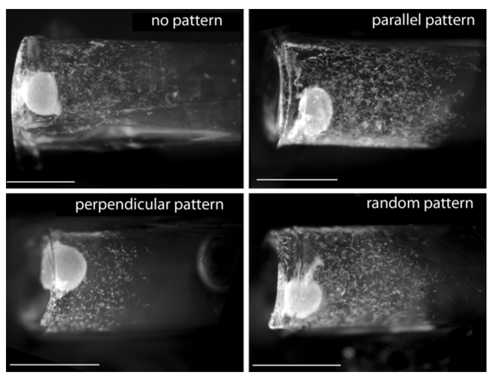

Figure 3: Schwann cells and neurons growing on various topographically enhanced polymers that have been wrapped around a cylinder.

4.3 Methods for Comparison and Validation

The current state of the art for determining directionality of neural growth comes from Bruder et al. These techniques are purely two-dimensional, but will be used as a basis for validating the three dimensional techniques proposed here. For comparison to occur, the two dimensional orientation vectors produced by Bruder's method will be embedded in three-space and compared directly to the long axis of the orientation ellipsoid computed in our methods.

Three dimensional proximity and density values will also be compared to those achieved from image analysis techniques. The goal here is to quantify how much volumetric information is lost using the two dimensional analysis. The critical variable in this case is the inter-slice distance of the images.

4.4 Scientific Visualization Contributions

The utility of ellipsoid-fitting algorithms to describe directionality in volumetric datasets has been made clear in previous work dealing with diffusion tensor imaging Malloy-2006-NWM. However, to our knowledge, these techniques have not been applied in an attempt to describe directionality or alignment of cells within a volume. Measuring the effectiveness of this technique within the given scientific setting is a novel undertaking, and could lead to more generalizable methods for analyzing cellular patterns and interactions in three dimensions.

Another notable visualization aspect of this application will be the analysis of the cellular data on both the global and local levels. The ability to evaluate the directionality of each individual cell, or small clusters of cells, and compare it with the collective alignment of the entire cell colony provides a robust visualization environment that takes advantage of the data in such a way that both global and local features are preserved. Once the local and global alignments are determined, visual feedback of the deviation of local alignments from the global alignment will be displayed. A number of icon-based techniques will be tested for effectively displaying these alignment variations.

5 Impact

Damage to the spinal cord is arguably one of the most debilitating and untreatable types of injury. Based on recent statistics, there are approximately 11,000 spinal cord injuries in the United States each year and over 250,000 Americans living with spinal cord damage. It's clear from these statistics that developing methods for in-vivo nerve regeneration would better the quality of living for a significant number of people.

From a computational perspective, the three-dimensional techniques for quantifying cellular growth and alignment are not limited to the scientific context of this application. The proposed techniques could generalize to countless types of cells, and would undoubtedly prove useful in other application areas.

6 Research Plan

We provide a reasonable schedule of well-defined milestones to track progress:
Week 1: Develop and implement proximity and density measurements within the volumetric data.
Weeks 2-3: Develop and implement ellipsoid-fitting methods for both global and local alignment metrics.
Week 4: Validate methods by comparing to 2D state-of-the-art. Implement visual techniques for displaying variation.
Week 5: Collect feedback from expert users.
Week 6: Fine tuning and preparation for final presentation.

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Experience

Computer Science Researcher at Brown University — Providence, RI
Summer 2006, June 2007 - present

- Developing a software package that will allow scientists to view and interact with high resolution videos of 3D skeletal models.
- Responsible for implementing, testing, and optimizing various software tools used to capture and analyze motion data.
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Instructor of Mathematics at Groton School — Groton, MA
June 2006 - June 2007

- Taught AP Calculus, Geometry, and Algebra 2/Trigonometry, as well as an introductory programming course.
- Served as assistant coach to the varsity basketball and baseball teams.

Software Engineer at Mad Doc Software, LLC. — Andover, MA
June 2005 - June 2006

- Responsible for creating and maintaining several game systems for the PC and Microsoft XBox 360 title *Star Trek Legacy*, published by Bethesda Softworks.
- Developed various modes of online play, maintaining network-safe code.
- Aided in the communication between designers and developers, regularly presenting new ideas and algorithms to the production team.

Academic Honors

- Member of Pi Mu Epsilon (Mathematics Honor Society) and Phi Beta Kappa.
- Awarded the Gertrude McBrien Medal as the top mathematics student at Holy Cross.
- Awarded a Summer Research Fellowship in Science and Mathematics from the Council on Undergraduate Research.
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August, 2001- May, 2005

RESEARCH INTERESTS Utilization of computational and visualization tools for medical imaging applications, including computed tomography (CT) and magnetic resonance imaging (MRI).

RESEARCH Scientific Visualization Group Brown University (Dr. David Laidlaw)

EXPERIENCE - Developing metrics to characterize wrist kinematics and study the effects of motion within both healthy and pathological populations. (January, 2007 - Present)

High Resolution Functional MRI Laboratory Brown University (Dr. David Ress)

- Modeled cerebral blood flow at the capillary level through the use of high resolution functional magnetic resonance imaging and mathematical models that included electrical circuit component equivalents. (August, 2005 December, 2006)

Vanderbilt University Institute of Imaging Science Vanderbilt University (Dr. John Gore and Dr. Thomas Yankeelov)

- Utilized dynamically contrast enhanced (DCE) MRI to track treatment efficacy of breast cancer. Developed a general graphical user interface for MRI viewing for non-technical uses.

PROFESSIONAL EXPERIENCE Teaching Assistant Brown University Department of Biology and Medicine. Organ Replacement (Spring, 2007) and Genetics (Fall, 2006)

Product Applications Engineer - Research Systems Incorporated (Boulder, Colorado). Developed applications and demonstration for automated analysis of CT and MRI images (Summer 2005)