

Friday, April 21, 2017 12:00 pm - 5:00 pm SDSU's Parma Payne Goodall Alumni Center

For Applied Computational Sciences and Engineering & Computational Science Curriculum Development





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11:30am-12:00 pm	Registration	
12:00-1:00 pm	Buffet Lunch	
	Satchi Venkataraman, Associate Director Computational Science Research Center San Diego State University	Moderator
1:00-1:10 pm	<b>Stanley Maloy, Dean</b> College of Sciences San Diego State University	Welcome / Opening Remarks
1:10-1:30 pm	Jose E. Castillo, Director and Ezra Bejar, Industry Projects Coord. Computational Science Research Center San Diego State University	Computational Science at SDSU and ACSESS Program
1:30-2:30 pm	<b>Greg Davis (Bio)</b> Mechanical Systems (Div 35) Chief Technologist Planetary Protection Architect, Europa Lander Jet Propulsion Laboratory	Keynote Speaker "The Importance of Advanced Modeling and Simulation for Developing 21st Century Spacecraft"
2:30-3:00 pm	Blitz Oral Presentations Introduction by Antonio Redondo, Los Alamos National Laboratory	
3:00-3:45 pm	Poster Presentations / Reception	
4:00-4:30 pm	Paul Paolini, Satchi Venkataraman, and Andrew Cooksy Associate Directors Computational Science Research Center San Diego State University	Poster Presentation Awards and Closing Remarks
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### **Computational Science Research Center**



We cordially welcome our local tech and biotech industry executives, board members and CSRC faculty, and students to our Applied Computational Science and Engineering Student Support (ACSESS) Annual Event.

ACSESS was created thirteen years ago to provide graduate students an opportunity to work on real world problems. Also, with the vision to create stronger links between academic computational scientists, industry professionals and technology officers. This year's program is a reflection of that idea to continue the support and aspiration to foster CSRC educational and research missions; instilling graduate students interest in industry problems and pursuing careers in technology and biotechnology sectors.

We appreciate the great interest of our authorities, faculty and student participation in our event, and our special thanks go to our CSRC board members for their continuous advice, as well as our company sponsor's for the financial commitment to our teaching and research missions.



The mission of the Computational Science Research Center (CSRC), located at San Diego State University, is to promote development and advancement of the interdisciplinary subject of computational science. This is accomplished by fostering research, developing educational programs, and promoting industrial interaction, outreach, and partnership activities.

The Computational Science Research Center provides an excellent environment for scientific research at SDSU. The center facilitates the interaction between applied mathematics, computer science, and the sciences by providing the necessary infrastructure for productive research efforts.

Real world applications are the focus of the projects undertaken by the faculty and students of the center. Such projects provide a significant educational opportunity for our students to hone their industrially relevant computational skills.

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Alfonso Limon Chief Liaison, Research and Development Oneirix Labs Notes on Misspecifying the Random Effects Distribution Regarding Analysis Under a AB/BA Crossover Trial in Dichotomous Data

#### **By: Lixia Zhu and Kung-Jong Lui** Advisor: Kung-Jong Lui

When comparing two treatments under a AB/BA Crossover Trial in Dichotomous data, a random subject effects logistic regression model is often used to analyze such data. There are strong and parametric assumptions of normally distributed random subject effects in most cases. In reality, this may not be true. The impacts of misspecifying a random effects distribution on hypothesis test, point estimates and interval estimates are investigated in this paper. Monte Carlo simulations are used to simulate the study data under nine different random effects distributions. Assuming the normality of the random effects, we use maximum likelihood to analyze the simulation data. The simulation results suggest that the impacts depend on the variance of random effects and the sample size. The impacts can be negligible when the variance of random effects are small and the sample size is large. However, the impacts can be substantial when the variance of random effects are large and the sample size is small. The data taken from a two-period crossover trial comparing the placebo and the active drug for the safety of the disease cerebrovascular deficiency are used to illustrate the impacts here.

#### This research is supported by the Computational Science Research Center at San Diego State University.

#### Spectroscopic Ellipsometry for Anisotropic Nano-layered Al/SiO2 Metamaterial

#### **By: Priscilla Kelly, Andrew Martin, and Lyuba Kuznetsova** Advisor: Lyuba Kuznetsova

Manufacturing CMOS-compatible metamaterials capable of hyperbolic dispersion is a goal of optical and material research. This type of dispersion occurs when a material's dielectric constants have opposite signs in the parallel and perpendicular directions. Theoretically, this opens a multitude of photonic states, which can be used in applications such as blue/UV LEDs. This research investigates the affect of power, pressure, and temperature on the dielectric constants of Al/ SiO2 layered structures grown with RF sputtering. Using the 4x4 transfer matrix method, we predict dielectric constants in three dimensions by fitting data from a RC2 Ellipsometer (A.C. Woollam Co.) with the goal of developing hyperbolic dispersion.

This research is supported by National Science Foundation funds (GRFP, ID: 1321850), and the Computational Science Research Center at San Diego State University.

### Design of a Hybrid-MAC Scheme for Multi-Beam Antenna in OPNET

### By: Shivam Garg, Nandini Venkatraman, Soroush Tamizi, and Hira Shah

Advisor: Sunil Kumar

The proliferation of mobile users and the increased use of the multimedia applications over wireless has caused the wellknown and the intensely-researched problem of spectrum crunch. Existing network infrastructure can not support these application data demands. The transport of this exponentially increasing amount of data in a timely and secure manner, without compromising the quality of service and user experience, is a big challenge for researchers in wireless communication and networks. Major research groups, government agencies, and corporations are investigating significant resources for addressing this issue. Qualcomm has termed this as the "1000X" challenge to represent the 1000 fold increase in wireless network data rates needed in near future.

Recently, the use of directional antennas (e.g., the multi-beam smart antennas (MBSA)) which allow the spatial reuse and interference mitigation has been investigated for alleviating the spectrum crunch. Using 'm' beams in MBSA, m users can be simultaneously supported by a node in wireless networks, as opposed to only one user in existing omni-directional antenna based schemes. This can increase the spectrum efficiency by up to m times.

In this research, we propose a novel, medium access control protocol (MAC) based on the use of MBSA in wireless nodes. This abstract is mainly focused on enhancements done at the Physical and MAC layers to support the simultaneous data transport of multiple users by taking advantage of MBSAs. We have implemented a directional MAC scheme in the Riverbed wireless modeler, which is a widely-used discrete event network simulator software. Note that the Riverbed modeler has implemented the physical and MAC layer protocols only for the omni-directional protocols. We have made significant changes in this modeler to incorporate the use of MBSA and new MAC layer protocols.

## *This research is supported by Department of Defense funds* (*FA8750-14-1-0075*).

#### Metabolic Model and Data-Driven Exploration Linking Genotypes to Phenotypes

### By: Daniel Cuevas, Rebecca de Wardt, Thiago Bruce, and Elizabeth Dinsdale

Advisor: Robert Edwards

Current bioinformatics trends show a shift toward understanding an organism as a functional, metabolic entity rather than only through the lens of its genetic landscape. However, due to the complexity of individual data sets that describe genome annotations and phenotypic results it is often difficult to evaluate an organism in the context of its genome with its metabolism. Functional genomic studies are supplemented by in silico genome-scale metabolic models to explore the metabolism of an organism using Flux-Balance Analysis (FBA). Based on the organism's metabolic-associated genes, these models allow the exploration of metabolic flux through an entire metabolic network. PyFBA, an extensible Python-based open-source software package (http://linsalrob.github.io/PyFBA), provides the platform to reconstruct the metabolic map, perform FBA on several media conditions, and refine the metabolism through network gap-filling. PyFBA enables the novel assessment of phenotypic results in the setting of accurate genome-scale metabolic models.

With our collection of more than fifty diverse bacteria that have been sequenced, annotated, and grown on over 100 minimal media compositions (http://edwards.sdsu.edu/dbbp), we have begun to investigate methods in connecting genotypes to phenotypes. Functional annotations performed on the RAST pipeline are tied to the biochemical reactions contained within the PyFBA metabolic model. Data visualizations of metabolic flux rates are viewed within the perspective of protein functional groups and metabolic pathways. Quantifying genetic composition, growth dynamics, and metabolic phenotypes facilitates microbe-microbe statistics and comparisons. By linking a microbe's genotype to its phenotype, new methods arise to characterize and compare microbes not yet explored by traditional bioinformatics approaches.

This research is supported by National Science Foundation funds (MCB-1330800 and CNS-1305112), and the Computational Science Research Center at San Diego State University.

#### Bacteriophage Lifestyles: Capsid Size Matters -- A Predictive Mathematical Model for Environmental Data

## *By: Diana Y. Lee, Kate McNair, Robert Edwards, and Antoni Luque*

Advisor: Antoni Luque

Bacteriophages are superabundant in nearly all environments on Earth, from the deep sea to the human gut. Details on distribution of bacteriophage structures could lead to better understanding of which phages are more successful in various environmental niches and a richer understanding of their impact. With the advent of large datasets of phage genome data being produced via metagenomics, a high-throughput model to produce these distributions based on genome size would be ideal. We present an approach to such a model here. The model was developed using attributes of icosahedral tailed phages in order to address a majority of phages with one precise, repeatable method applicable to large data sets. Application of the model to these data sets produced distributions of T-numbers that closely match cited percentages for capsids expected to be icosahedral, and identified those groups with non-icosahedral capsid shapes. This result is promising, and leads to other lines of inquiry in order to refine the model, create related models for other phage groups and investigate what we can learn about the variance in capsid structure distribution.

This research is supported by National Science Foundation funds (DUE-1259951), University Grants Program, and the Computational Science Research Center at San Diego State University.



#### **Evaluation of NanoSyringes for Therapeutic Delivery**

#### **By: Iara Rocchi, Sinem Beyhan, and Nicholas Shikuma** Advisor: Nicholas Shikuma

Over millions of years, microbes have evolved diverse strategies for interacting with host cells in a targeted and controlled manner. Our lab aims to exploit these strategies, which can provide valuable inspiration and resources for new technologies in biomedicine. We recently discovered a class of nanometerscale syringe-like structures, termed NanoSyringes, that bear similarity to the tails of bacteriophage and stimulate the development of a marine invertebrate. Based on their unique ability to directly interact with eukaryotic cells, we sought to repurpose NanoSyringes for biotechnology purposes. Here we show that NanoSyringes possess the ability to cause cell death in mice derived macrophage cell lines within 8 hours. Moreover, we hypothesize that this death phenotype is mediated through a gene encoding proteinaceous cargo that is delivered to macrophages through the NanoSyringe structure. These findings are transformative because NanoSyringes have the potential to be developed as novel therapeutic delivery systems.

## *This research is supported by Office of Naval Research funds* (*N00014-16-1-2135*).

Systematic Comparison of Two Topologies for Multistage Sequentially Rotated Wideband Circularly Polarized High Gain Microstrip Patch Array Antennas at Ku-Band

# By: Roshin Rose George, Alejandro T. Castro, and Satish K. Sharma

Advisor: Satish K. Sharma

A wideband circularly polarized high gain microstrip patch array antennas at Ku-band are investigated and compared by incorporating both unequal and equal power division based feeding networks. Four stages of sequential rotation is used to create 16×16 patch array which provides wider common bandwidth between the impedance matching (S11 < -10dB), 3dB axial ratio and 3dB gain of 12.3% for the equal power divider based feed array and 13.2% for the unequal power divider based feed array in addition to high polarization purity. The high peak gain of 28.5dBic is obtained for the unequal power division feed based array antennas compared to 26.8dBic peak gain in the case of the equal power division based feed array antennas. The additional comparison between two feed networks based arrays reveals that the unequal power divider based array antennas provide better array characteristics than the equal power divider based feed array antennas. An 8×8 array is fabricated, measured for its circuit characteristics and radiation characteristics which found to be in close agreement with simulated results.

### An Intragranular Microfracture Model for Geologic Sequestration of CO2

## By: Jonathan Matthews, Christopher Paolini, and Jose Castillo

Advisor: Christopher Paolini

A model for simulating microfracture evolution in reservoirs used for geologic sequestration of CO2 is presented. The model is coupled to a reactive transport simulator that models the solid mineral composition as a collection of spherical grains. Seed fractures are randomly assigned to these spherical grains in each volume cell of a finite volume domain modeling a brine saturated reservoir with a shale caprock layer. These seed fractures are allowed to propagate according to the Griffith fracture criterion. Stress intensities induced by CO2 injection are determined via a poroelastic finite element model. The discrete microfracture data generated by the model is coupled to geophysical and geochemical models. For geophysical properties, we utilize Oda's permeability tensor to upscale the incremental effects of microfractures on the reservoir and caprock permeability. The surface areas of modeled microfractures increment the reactive surface area of minerals in the geochemical model, altering the rate of dissolution and precipitation of minerals on the grain surfaces. Results of a CO2 injection simulation are presented.

This research is supported by US Department of Energy, National Energy Technology Laboratory funds (DE-FOA-0000032), and the Computational Science Research Center at San Diego State University.



#### Surface Waves over Arbitrary Vorticity Profiles

#### **By: Robert Insley and Christopher Curtis** Advisor: Christopher Curtis

The purpose of this project is to simulate the effects of large numbers of point vortices on free fluid surfaces. To accomplish this, we couple vortex methods, which are based on the vorticity equation and the Biot-Savart law, to the Unified Transform Method and the Dirichlet-to-Neumann operator, thus providing a novel formulation through which to perform computations of the fluid flow. This method is ultimately formulated in terms of vortex coordinates and surface variables, and compares far favorably to less-efficient methods that have to keep track of entire vector fields. The ability to calculate the behavior of elaborate underwater vortex groupings opens doors to new research. For example, it could be used to examine the effects of underwater eddies on passing tsunamis, or to model the transport of substances in water (such as pollutants) by vortices.

This research is supported by National Science Foundation funds (DUE-1259951), and the Computational Science Research Center at San Diego State University.

#### *Efficient Signal Recovery for Solving Large-Scale Factorized Linear Systems*

#### **By:** Anna Ma, Deanna Needell, and Aaditya Ramdas Advisor: Deanna Needell

Stochastic iterative algorithms such as the Kaczmarz and Gauss-Seidel methods have gained recent attention because of their speed, simplicity, and the ability to approximately solve large-scale linear systems of equations without needing to access the entire matrix. In this work, we consider the setting where we wish to solve a linear system in a large matrix X that is stored in a factorized form, X = UV; this setting either arises naturally in many applications or may be imposed when working with large low-rank datasets for reasons of space required for storage. We propose a variant of the randomized Kaczmarz method for such systems that takes advantage of the factored form, and avoids computing X. We prove an exponential convergence rate and supplement our theoretical guarantees with experimental evidence demonstrating that the factored variant yields significant acceleration in convergence.

This research is supported by National Science Foundation Career funds (1348721), the Computational Science Research Center Intellisis Fellowship, and Edison International Scholarship.

#### Optimal Electrode Selection for Damage Identification in Carbon Fiber Reinforced Polymer Composites using Electrical Resistance Tomography

#### By: Luis Waldo Escalona Galvis, Paulina Diaz-Montiel, and Satchi Venkataraman

Advisor: Satchi Venkataraman

Damage modes in laminated fiber reinforced composites include intralaminar matrix cracking, interlaminar delamination and fiber failure. Identifying and quantifying the extent of damage during service is paramount to the safe operation of these structures. Electrical Resistance Tomography (ERT) is being used as non-destructive evaluation (NDE) technique to assess internal damage in Carbon Fiber Reinforced Polymer (CFRP) composite structures. The ERT technique uses the inherent electrical properties of CFRP for the sensing and characterization of internal damage state in composites with conductive fibers. Sensing delamination and matrix cracking are particularly challenging as they have to rely on the transverse to fiber direction conductivity, which is one to two orders of magnitude lower than the fiber direction electrical conductivity.

This work investigated optimum selection of sensing configurations for delamination detection using ERT in thick cross-ply laminates. The use of an effective independence (EI) measure originally proposed for sensor location optimization in experimental vibration modal analysis is explored. The EI measure is applied for selecting the minimum set of resistance measurements obtained from all the possible electrode combinations used in the excitation of the laminate. A spectral representation of the resistance measurements in the laminate obtained after applying Singular Value Decomposition (SVD) is used for the implementation of the EI based reduction. The electric potential field in the CFRP laminates is computed numerically by finite element models considering different lavouts under delamination damage with specified sizes and locations. The effectiveness of the EI based reduction in electrode combinations reduction is assessed by comparing the results of inverse identification of damage using the full set to the reduced set of resistance change measurements.

This work demonstrated that the EI measure is effective for the optimal selection of electrode pairs needed for damage identification using ERT on CFRP composite laminates.

This research is supported by the Computational Science Research Center at San Diego State University. RISP: A Reconfigurable In-Storage Processing Framework for Big Data Analysis

**By: Xiaojia Song and Tao Xie** Advisor: Tao Xie

Existing host-centric data processing architectures are inadequate to some big data analytics for two reasons. First, application performance is not optimized as data transfer between an external storage device and a host accounts for a large proportion of execution time. Second, energy efficiency is low. Further, new features of emerging NVM (non-volatile memory) like byte-addressability cannot be fully exploited by a traditional data processing architecture. To solve these issues, in-storage processing, which offloads computation to an NVMbased external storage device, has been recently proposed. However, existing in-storage architectures injudiciously devote all hardware resources to improving performance for applications with various features, which incurs an unnecessarily high energy consumption. In this research, we propose a new data processing architecture called RISP (reconfigurable instorage processing) to alleviate the problem. In addition, it can fully utilize the new features of the emerging NVM. Instead of using embedded CPUs to process data, RISP employs FPGA in charge of data processing so that data transfer and processing could work in a pipelined manner. Hardware resources in RISP can be dynamically reconfigured according to the features of applications in order to achieve a high performance with a low energy consumption. The results show compared to the hostbased data analysis RISP obtains more than 5x performance improvement and 2 -160x energy consumption reduction for the three applications. The reconfigurable functionality could deliver an extra energy gain with 0.2-77.17% at the same time without performance loss.

#### This research is supported by National Science Foundation funds (CNS-1320738), and the Computational Science Research Center at San Diego State University.

#### W-Band Feed Horn with Polarizer Structure for an Offset Reflector Antenna for CubeSat Applications

#### By: Ghanshyam Mishra

Advisor: Satish K. Sharma

A compact W-band cylindrical waveguide horn antenna with polarizer structure is designed which offers wideband left-hand circular polarization (LHCP) and symmetric radiation pattern. It has wideband impedance matching below S11= -15 dB and axial ratio below 1.8 dB from 79.5 GHz to 87.5 GHz. This horn is used as a feed source for an offset parabolic reflector. The reflector antenna provides peak RHCP (right-hand circular polarization) directivity of 37.3 dBic at 86 GHz.

#### This research is supported by Office of Naval Research funds.

#### Ab Initio Calculations of Gamow-Teller Transition Strengths

#### By: Jordan Fox

Advisor: Calvin Johnson

Recent years have seen a tremendous improvement in rigorous ab initio methods for nuclear physics. Ab initio calculations differ from phenomenological models in that they start from two-body scattering data rather than being tuned to manybody spectral data, allowing for a more fundamental and robust description of many-body properties. The first step in my investigation is to analyze changes in Gamow-Teller transition strength functions -- a particular kind of beta-decay -- for increasing size of the model space. By using our configurationinteraction code, I have tested so-called effective interactions by computing many-body spectra for nuclei as well as transition strengths for Gamow-Teller transitions in the p-shell and sdshell. These preliminary tests provide a foundation for effective theory analysis and further development of ab initio framework.

This research is supported by U.S. Department of Energy funds (DE-FG02-03ER41272), National Science Foundation funds (DUE-1259951), and the Computational Science Research Center at San Diego State University.



Diagnostic Prediction of Autism in Resting-State Functional MRI using Conditional Random Forest

#### By: Afrooz Jahedi, B. T. Faires, C. A. Nasamran, and R.-A. Müller

Advisor: Juanjuan Fan and Ralph-Axel Müller

Autism spectrum disorder (ASD) is characterized by social and behavioral impairments. Although it is a neurodevelopmental disorder, no unique brain biomarkers for ASD are known. Previous research has used machine learning and computational statistics to mine MRI data for ASD biomarkers. Chen et al. (NICL 2015) achieved 90.8% diagnostic accuracy using the ensemble learning technique, random forest (RF). However, RF is known to have an intrinsic variable selection bias (Strobl et al., BMC Bioinformatics 2007). In order to eliminate this bias and to increase the interpretability of the results, we developed a conditional random forest (CRF) ASD diagnostic prediction model for resting-state functional MRI data (rs-fMRI).

Rs-fMRI data from 252 patients (126 ASD and 126 TD) were selected from the Autism Brain Imaging Data Exchange (ABIDE). Preprocessing techniques and participant selection criteria were adopted from Chen at al. to allow for direct comparisons between the RF and CRF models. Connectivity matrices for each participant were created using 220 regions of interest (ROI) from Power et al. (Neuron 2011). The dimensionality of the dataset was reduced to eliminate noise and for computational feasibility.

The CRF model achieved a diagnostic accuracy of 92.5-95% (in two runs with different seeds) from 180 most informative connections between ROIs. Most informative connections (normalized based on total number of possible connections per network) were heavily represented in somatosensory/motor (especially mouth region), ventral attention, salience, cingulo-opercular, memory retrieval, and cerebellar networks. Raw numbers for default mode network (before normalization) were also high.

CRF reached very high, though not perfect, diagnostic prediction accuracy based on a complex set of 180 functional connectivities. Reduced variable selection bias compared to the earlier RF study (Chen et al., 2015) resulted not only in slightly improved accuracy, but also in some changes in the relative network composition of most informative connections. Whereas preponderance of somatosensory ROIs was slightly lower for CRF (compared to RF), cingulo-opercular, ventral attention, and cerebellar ROIs were found to be more informative. Overall, the findings suggest that rs-fMRI data may be a source for complex biomarkers of ASD.

This research is supported by National Science Foundation funds (R01-MH081023 and R01-MH101173).

#### Modeling Multiphase Buoyancy Driven Plume Migration during Geologic CO2 Injection

#### **By: Kyle Campbell, Christopher Paolini, and Jose Castillo** Advisor: Christopher Paolini and Jose Castillo

Geologic CO2 sequestration requires that no more than 1% of injected CO2 escape within 1000 years after injection. To predict long-term retention of CO2 in a reservoir, the interaction of geochemical and geomechanical effects of injection must be investigated through numerical simulation. The transport of gas phase CO2 through micrometer scale fractures in porous sandstone and shale caprock is one concern that could lead to unwanted release of injected CO2 into the atmosphere. We model the buoyancy driven flow of a twophase system consisting of a CO2-H2O vapor mixture phase and an aqueous phase composed of formation water, dissolved CO2, and charged solutes formed from the dissolution of quartz, feldspars, carbonate, and clay minerals. This twophase system forms a plume of CO2 that can migrate upward due to differences in density between CO2-rich phases and the surrounding formation fluid. We model the gas phase CO2-H2O composition using a Redlich and Kwong equation of state (EOS) with mixing rules, and the aqueous phase composition using the revised Helgeson Kirkham Flowers model for approximating thermodynamic properties of aqueous electrolytic solutions at high temperature and pressure. Water density and electrostatic properties are computed using the virial EOS developed by Haar, Gallagher, and Kell outside the critical region and the Levelt and Sengers EOS within the critical region. Pitzer equations are used to compute osmotic and solute activity coefficients.

This research is supported by National Science Foundation funds (DUE-1259951).



#### Cortical Connectivity Analysis of Primate Brain Using Graph Learning on ECoG Signals

#### **By: Siddhi Tavildar and Ashkan Ashrafi** Advisor: Ashkan Ashrafi

Finding cortical neural connectivity remains one of the major challenges of computational neuroscience. In the present work, we propose a method based on the new signal processing concept of Graph Signal Processing to estimate the functional connectivity of primates' brains from Electrocorticography (ECoG) signals alone. In this method, we model ECoG electrodes as nodes of a graph whose edges represent the cortical connectivity. The ECoG signals are considered the signals on the graph. The autoregressive models of the recorded ECoG signals are used to infer the underlying graph. The method is based on maximizing the graph smoothness, which is defined as the quadratic graph Laplacian. The outcome of this optimization algorithm is the Laplacian matrix of the graph, which will be used to obtain an undirected adjacency matrix of the graph. The adjacency matrix represents an estimate of the cortical connectivity map of the brain area in which the ECoG electrodes are placed.

Although we observed certain spontaneous variations in the connectivity map of the brain, the consistent connections were identified with their high probability of occurrence. The results of graph-learning algorithm were compared with the cortico-cortical electric potential (CCEP) map of the same monkey and we found 55% correlation in the left hemisphere and 69% correlation in the right hemisphere. We were also successful in detecting the cross hemispherical connections using the proposed graph learning algorithm. We were able to identify the strong connections throughout all experiments on the same monkey, recorded on different days. With this result, we argue that the method can be used to track the changes in the cortical connectivity map occurring over time.

This research is supported by National Science Foundation funds (EEC-1028725), and the Computational Science Research Center at San Diego State University.

#### Modeling Phage-Bacteria Dynamics in Mucus: A Multiscale Approach to Phage Therapy

#### **By: Kevin Joiner and Antoni Luque** Advisor: Antoni Luque

In recent times, phage therapy has emerged as a promising and sustainable alternative to antibiotics. To explore optimal phage treatment regimens in the natural environment we have developed an agent based computational model of the E. coli bacteria and T4 bacteriophage in mucus. The model will be used to analyze three important aspects of phage therapy; phage encounter rates with bacteria, population dynamics and the bacteria-phage arms race. In the project's first stage, phage and bacteria encounters are analyzed using contact times during their stochastic motion. The phage's motion, due to its adherence to mucus, is described via a continuous time random walk with power law waiting times. The motion of the E. Coli is composed of alternating stages known as run and tumble, whose durations follow an exponential probability distribution. Encounters between the bacteria and phage are detected using a multiscale collision algorithm. For the second aspect of our research, the simulations will include phage and bacteria lifestyles. To overcome the workload imposed by large population numbers and long timescales a dynamic, high performance computational environment will be used to simulate the bacteria-phage ecosystem. Our third goal is to extend the model towards evaluating the mutative abilities of phage in overcoming eventual bacteria resistance. Here, stochastic state variables in phage and bacteria cells will be used to evaluate the resistance of phage against bacterial evolution. Throughout the project, model calibration will be accomplished using empirical T4 and E. Coli data obtained from the Viral Information Institute at San Diego State University. If successful, our research will advance phage therapy as a viable method to destroy harmful bacteria.

This research is supported by Department of Defense Smart Program funds, and the Computational Science Research Center at San Diego State University.



#### The Strangeness of Neutron Stars

#### **By: William Spinella and Fridolin Weber** Advisor: Fridolin Weber

Neutron stars are the super-dense remnants of very massive stars (10 to 25 times the mass of our sun) whose life cycles end in a supernova explosion. They provide a means to study the nature of matter at densities far beyond those attainable with terrestrial experiments. In the core of a neutron star the density is so extreme that atomic nuclei dissociate into their constituent baryons (neutrons and protons). Due to the Pauli Exclusion Principle of Quantum Mechanics, these baryons reach extremely high energies, and particle reactions that favor the creation of exotic baryons called hyperons are likely to occur. Hyperons, such as the Lambda, Sigma, and Xi baryons, differ from neutrons and protons and all the matter we interact with in that they possess at least one constituent strange quark.

To model neutron star matter we use the relativistic mean-field theory in which baryons (neutrons, protons, hyperons) interact through the exchange of particles called mesons, and the strength of these baryon-baryon interactions is scaled by the mesonbaryon coupling constants. The meson-hyperon coupling constants governing the attractive part of baryon-hyperon interaction can be somewhat constrained by experiment. However, at this time the coupling constants responsible for the repulsive part of that interaction are constrained only by the bulk properties of neutron stars.

In our current work we are investigating the repulsive mesonhyperon coupling space using parameterizations consistent with the current constraints on nuclear matter at saturation density (e.g. SW1, GM1L, and DD2). Of particular interest is the region of the coupling space for which the model reproduces a neutron star with a maximum mass that satisfies the constraint set by PSR J0348+0432, observed to have a mass approximately twice that of our Sun. Also of interest is the strangeness fraction of neutron stars (fraction of strange quarks to total quarks). Our results indicate that the strangeness fraction may be substantial, and show strangeness hot spots that consistently

appear in the same region of the coupling space for different nuclear

parameterizations.

This research is supported by National Science Foundation funds (PHY-1411708), and the Computational Science Research Center at San Diego State University. SubFlow: Modeling Geological Sequestration of Carbon Dioxide with Mimetic Discretization Methods

#### *By: Johnny Corbino, Christopher Paolini, and Jose Castillo Advisor: Jose Castillo and Christopher Paolini*

Climate change is a scientific fact, not a rumor. The primary cause of climate change is the combustion of fossil fuels, which emits greenhouse gases (GHG). These gases trap the infrared radiation in the atmosphere rising the average temperature on the surface of the Earth. According to the Environmental Protection Agency (EPA), carbon dioxide (CO2) represents about 81% of the total amount of anthropogenic GHG in the atmosphere. The Department of Energy (DOE) and the EPA have proclaimed the geological sequestration of CO2 as an important measure to decelerate climate change.

In this work, we introduce a reliable software package to simulate the long term storage of CO2 injected into geological formations. Depleted oil fields and subsurface saline aquifers are examples of this type of formations, they possess the necessary characteristics (permeability, porosity, geometry, etc.) to retain the maximum amount of CO2 trapped for a relatively long period of time (millennia). The software that we are developing (SubFlow), takes into account all these required parameters in order to predict whether or not a preselected injection site is in fact suitable for CO2 sequestration.

SubFlow stands for "Subsurface Flow simulator", and it is conceived as an open-source, sustainable, and reliable software element that allows its users to model the transport of reactive chemical compounds (CO2, H2S, etc.) in porous media. Through SubFlow, the user can construct these injection scenarios by specifying their geometry, physical and chemical composition, and the location of the injection wells (depth, rate of injection, concentration, etc.). However, what makes SubFlow different from the rest is its numerical core (the module that actually solves the problem's governing equations).

In our software, we use a novel numerical approach to solve the main partial differential equations (PDE) that governs the migration of reactive compounds in porous media at typical injection depths. We use mimetic discretization methods (MDM) to attain higher-order accurate simulations without compromising the physical constraints inherent to the problem. For this type of problem, MDM have proven to be a versatile and competitive alternative to the widely used standard finitedifference (FDM) and finite element (FEM) methods.

This research is supported by National Science Foundation funds, and the Computational Science Research Center at San Diego State University.

#### Mixed Mode Delamination Growth under Fatigue Loading in Composites using a Cohesive Zone Approach

#### **By: Beniamino Cimmino and Satchi Venkataraman** Advisor: Satchi Venkataraman

One of the most common failure modes for laminated composite structures is delamination, or interlaminar cracking. The scope of this work is the development of a reliable and robust predictive numerical tool for delamination in carbon fibre reinforced polymer (CFRP) laminates under quasi-static and cyclic mixed mode loading. To characterize the onset and propagation of delamination, the use of a fracture mechanics approach known as Virtual Crack Closure Technique (VCCT) and a damage mechanics approach has become common practice. The main drawback of the VCCT technique is that crack initiation and short crack propagation cannot be predicted. In this study, the capabilities of the commercial finite element software Abaqus with the implementation of the Cohesive Zone Model (CZM) and the user defined material (UMAT) was assessed. Benchmark delamination propagation results for several specimen configurations were generated and compared with previous work. The results demonstrated that the Cohesive Zone Approach implementation in Abaqus was capable of accurately replicating the benchmark delamination growth results for static loading. Two main strategies were used in this work to implement Cohesive Zone formulation in Abaqus: continuum based approach using cohesive elements and surface based approach with cohesive behaviour. The sensitivity of the interface elements has also been tested with respect to input parameters, such as interface element length, initial stiffness, damage initiation criteria and energy dissipated due to failure. The behaviour of the delamination between two composite unidirectional layers has been also described by a user subroutine, which contains a failure criterion for delamination initiation and growth both for static and cyclic loading. The results showed a good agreement with Cohesive Zone formulation in Abaqus. The numerical model of the laminate has been described as an assembly of individual layers and interface elements. Each individual ply has been assumed as an orthotropic homogenized continuum.

This research is supported by AFOSR funds.

#### Identification of Halomonas-Like Traits as a Novel Biomarker for Nodding Syndrome-Like Epilepsy

#### **By: Vito Adrian Cantu, John Mokili, and Robert Edwards** Advisor: Robert Edwards

Nodding syndrome is a neurological condition of unknown etiology, affecting children between the age of 5 and 15 year, in onchocerciasis endemic areas in sub-Saharan Africa. NS is characterized by multiple epileptic seizures. Patients also experience cognitive and motor decline, wasting, stunting, behavior and psychiatric difficulties.

As part of a large effort to investigate the etiology of nodding syndrome associated epilepsy, blood plasma, buffy coat and cerebrospinal fluid samples were collected from eighteen afflicted children in the Titule, Democratic Republic of Congo. Plasma samples from nine healthy children from the same town were also taken as a control. All samples were treated to enrich viral DNA and sequenced using Illumina Hi-seq platform. The resulting DNA sequence reads from all samples were then concatenated and assembled using a custom iterative cross-assembly method to generate a library of 38,733 contigs. All individual samples were then mapped to this library and the number of hits counted to generate a 38,733 x 63 matrix. A Random forest model was then trained on this matrix to assert which of the contigs in the library better differentiate patients with nodding syndrome-like epilepsy patients from controls.

The Random Forest model was able to classify the samples with 100% precision and 100% recall. All of the top ten contigs that better distinguish cases and controls contain parts of the Halomonas elongata genome. In particular, the top contig contains the gene for a putative protein of viral origin flanked by Halomanas elongata genome, suggesting an insertion site for a virus.

Taken together, those results seem to indicate that an Halomanas elongata phage plays an important role in nodding syndrome.

This research is supported by National Institues of Health funds, and the Computational Science Research Center at San Diego State University. Temporal and Spatial Modeling of Cytosolic Calcium Fluxes in Cultured Isolated Neonate Ventricular Rat Myocytes

#### **By: Esteban Vazquez-Hidalgo and Parag Katira** Advisor: Parag Katira

Adult mammalian ventricular myocytes have a well-developed T-tubule network allowing for fast spatially homogeneous calcium diffusion through the cell. Calcium is necessary for muscle contractions. In cardiomyocytes, contractions initiate from a rapid increase in intracellular calcium concentrations [Ca2+]. Calcium triggers myofilament contraction by causing a conformational change in actin filaments allowing myosin to bind and thus begin the cross-bridge cycle (contraction). Briefly, Ca2+ transients start when sarcolemmal L-type channels open, allowing Ca2+ into the cell. This calcium triggers the additional release of stored Ca2+ from the sarcoplasmic reticulum (SR) via the ryanodine receptors (RyR). This release creates an approximate 10-fold increase in cytosolic free Ca2+. This amplification phenomena is knows as calcium-induced calcium release (CICR). The cytosolic calcium is then sequestered by the fast sarco/endoplasmic reticulum Ca2+-ATPase (SERCA) to restore SR calcium. The remaining calcium is removed to the extracellular space via the slow sodium-calcium exchanger (NCX) pump. Unlike adult cells, neonatal ventricular rat myocytes (NVRMs) lack a T-tubule network. Ca2+ diffusion is slower in NVRMs as Ca2+ diffuses from the cellular membrane to the SR. Our goal is to use mathematical models to understand changes in Ca2+ handling based on RyR silencing data. NVRMs were harvested from 1-day old Sprague-Dawley rats. Cells were enzymatically isolated with trypsin. The cells were plated and treated with siRNA to knock-down production of RyR. Western blot and RT-qPCR are used to quantify abundance of RyR, NCX, and SERCA. Ca2+ transients are recorded using confocal microscopy of cardiocytes loaded with fluo3. Cells were field stimulated at 50 mV for 50 ms once every 3 seconds to initiate transient. Experimental results for control cells agree with the model: 1) approximately 50% of cytosolic Ca2+ enters via the cellular membrane while 50% is released from the SR, 2) Ca2+ diffuses across the cytosolic space and upon reaching the SR, additional Ca2+ is released. In addition to modeling the control cell, experimental results from RyR knock-down experiments are utilized to modify the model. In RyR knockdown experiments, Ca2+ transients have decreased amplitudes (less Ca2+) and decreased Ca2+ removal rates. Western blot and RT-qPCR quantification show RyR is down-regulated by 60%. Additionally, compensatory effects are observed. SERCA expression is down-regulated by 30% while NCX is upregulated by 50%. We will incorporate these results to update model to gain a better understanding of calcium dynamics.

This research is supported by California Metabolic Research Foundation funds, and the Computational Science Research Center at San Diego State University. Are Corals Fractal? An Examination of Fractal Analysis Tools on Ecological Subjects

#### By: James Mullinix

Advisor: Antoni Luque

Fractal analysis is an exciting field in applied mathematics. Recently, many papers have indicated that corals exhibit fractal properties. We study 55 corals of multiple species, and conclude that it is unlikely that, generally speaking, corals exhibit fractal properties. To bolster our argument, we study common structures which are both non-fractal and fractal to determine the accuracy of our fractal utilities. Moreover, we study structures derived from mathematical concepts through to common ecological structures. The results are clear; our algorithm accurately captures fractal behavior for fractal materials, including biological structures, while for corals, we fail to capture fractal properties. In the end, our studies show that corals, as independent species, should not be expected to exhibit fractal properties. This study uses a computationally inexpensive algorithm which converges quickly and accurately, and we argue that use of more sophisticated algorithms is unnecessary in terms of identifying fractal properties, but may discover other interesting geometric textures, which should be studied.

This research is supported by National Science Foundation funds (DUE-1259951), and the Computational Science Research Center at San Diego State University.

Wireless Multimedia Relay Communications: A Context-Aware Approach to Compensate Relay's Power Resource

#### **By: Shuan He and Wei Wang** Advisor: Wei Wang

With the rapid growth of multimedia data volumes, mobile video becomes the dominating traffic in future wireless networks. How to provide high Quality of Experience (QoE) for mobile customers by leveraging communication context becomes a big challenge. In this research, a context-aware wireless multimedia relay solution is proposed to improve the user QoE and utility of base station simultaneously. The communication power of the relay device is compensated by economic incentives provided by the base station. The Stackelberg game model is used in our solution to ensure all players reach the Pareto optimality at the equilibrium state. At last, we show the feasibility of proposed solution with quantitative simulation results.

This research is supported by National Science Foundation funds (CNS-1463768), and the Computational Science Research Center at San Diego State University. An Energy Stable, Explicit High-Order Semi-Lagrangian Method Based on Discontinuous Spectral Element Method

### By: Hareshram Natarajan

Advisor: Gustaaf Jacobs

We present a semi-Lagrangian scheme to solve the advection equation in a discontinuous spectral element framework. The focus of this work is to develop a high-order, stable and conservative scheme to solve multidimensional transport equations. Forward time integration is performed along the characteristic curve of tracer particles which are seeded on the quadrature points within each element. The solution at the transported location is then interpolated back to the quadrature points. Local constraints ensure mass conservation and connectivity between elements. The scheme is tested in one and two dimensions. It is shown to conserve global mass and energy and h,p convergence is achieved.

This research is supported by AFOSR funds, and the Computational Science Research Center at San Diego State University.

#### PETSc Based Parallelization of the Fully 3d-Curvilinear Non-Hydrostatic Coastal Ocean Dynamics Model, GCCOM

#### **By: Manuel Valera and Neelam Patel** Advisor: Jose Castillo

Nearshore and stratified water physics phenomena have created a need for high-resolution coastal ocean modelling to accurately calculate hydrodynamic processes. Coastal Ocean models are computationally demanding due to multi-scale physics, non-hydrostatic pressure solving, and in our model, a fully 3D-curvilinear geometry. In this project, we present advances and strategies of integrating the Portable Extensible Toolkit for Scientific Computing (PETSc) library to existing serial code, which provides the MPI parallel framework to the General Curvilinear Coastal Ocean Model (GCCOM). We begin with the non-hydrostatic pressure solver where the serial model spends over 65% of its time. After incorporating PETSc in this solver, preliminary timing results show the model's potential in strong scaling. This prompts the parallelization of the entire GCCOM to improve overall performance. Recent developments that allow GCCOM to be a more robust application are also presented.

This research is supported by the Computational Science Research Center at San Diego State University. *Not All Matrix Elements are Equal: Comparing Shell-Model Interactions* 

#### By: Stephanie Lauber

Advisor: Calvin Johnson

Many-body calculations allow us to model nuclear properties such as spectra, including those well beyond experimental limits, through the use of interactions fit to data or derived from theory. These interactions describe hundreds of nuclear levels but a direct comparison between these sets offers little insight into the underlying physics. The number of single particle energies (SPEs) and two-body matrix elements (TBMEs) for a given model space range from dozens to hundreds, but not all parameters contribute equally to the resulting energy spectra. We aim to characterize these interactions based on the most important linear combinations of SPEs and TBMEs. Here I present the calculations for the most important linear combinations of the Brown-Richter USDB interaction in the sd-shell, which consists of 3 SPEs and 63 TBMEs. By performing a perturbative sensitively analysis using nuclei from Neon-20 through Argon-36, we were able to characterize the USDB interaction for comparison to other available sd-shell interactions.

This research is supported by Department of Energy funds (DE-FG02-03ER41272), National Science Foundation funds (DUE-1259951), and the Computational Science Research Center at San Diego State University.

#### Quasi-Dynamical Symmetries in Ab Initio Beryllium Nuclei

#### **By: Ryan Zbikowski** Advisor: Calvin Johnson

Recent advancements in supercomputers has allowed researchers the ability to compute nuclear many-body wave functions with tens of billions of components. In order to digest this vast numerical information, we decompose nuclear wave functions according to symmetry groups. This gives rise to recognizable and persistent patterns over many states. These quasi-dynamical symmetries are especially pronounced along rotational bands. We apply these decompositions to ab initio calculations of beryllium nuclei. These observations suggest group theoretical decompositions represent an additional means of characterizing nuclear wave functions, expanding understanding of nuclear anatomy, and the possibility of compact symmetry-adapted many-body bases for future calculations.

This research is supported by Department of Energy funds (DE-FG02-03ER41272), National Science Foundation funds (DUE-1259951), and the Computational Science Research Center at San Diego State University.

### Simulation of Progressive Failure of Composite Bolted Joints

#### **By:** Andrea Fontanelli and Satchi Venkataraman Advisor: Satchi Venkataraman

Composite materials are widely used in the aerospace industry due to their superior stiffness and weight-savings characteristics. Designing a reliable structure requires computational tools for predicting failure initiation and growth. Fiber reinforced laminated composites have complex failure modes. The failure initiate at the microscale level and their accumulation leads to mesoscale and macroscale failure. When the composite laminate is loaded beyond the critical threshold for damage initiation, at the microscale level failure cracks appears in the matrix, fiber, or fiber matrix interface. Depending on the loading direction, the relative stiffness, strength, and fracture toughness of the constituents the nature of these failure modes vary. Micromechanics based damage models that can capture these discrete failure events are computationally expensive and require multiscale simulation framework. The accumulation of microcraks as the stress level in the matrix is increased leads to macroscopic transverse ply cracks or fiber failures (intralaminar damage modes). The stress concentrations at the tips of the intra-laminar cracks can also develop delamination failure (inter-laminar damage modes). For computational efficiency, progressive failure analysis in composites is performed using continuum damage models (CDM). In CDM approach the development of cracks and the evolution of crack density is not directly considered. Instead these microscale cracks are considered to be smeared into the continuum and the homogenized response is described using thermodynamically consistent continuum damage variables. These variables are then used to account for the effect of microscale cracking on the ply level stiffness and strength properties.

This presentation will discuss the implementation of a CDM based progressive failure analysis considering only intralaminar damages, and its implementation as a user material UMAT subroutine for use with the ABAQUS<sup>™</sup> finite element analysis software. The Progressive failure analysis uses the Hashin criteria to predict failure initiation stress. Beyond this stress, damage variables are evolved for matrix and fiber damage. The progressive degradation of stiffness with increasing loads is performed using a linear energy base degradation scheme. The energy based degradation scheme is shown to significantly reduce mesh size sensitivity. The developed model is validated using experimental results for notched tensile specimens. The validated model was used to analyze the progressive failure analysis of composite laminate bolted joints.

This research is supported by AFOSR funds.

#### Mimetic Discretization Methods on Overlapping Grids

#### **By:** Angel Boada and Jose Castillo Advisor: Jose Castillo

Overture is a portable and flexible object-oriented framework for solving partial differential equations (PDEs). One of it features is the composite overlapping grid generation for solving problems that involve the simulation of complex moving geometry. Overlapping grids are a type of block structured body-fitted conforming grids that are used to resolve fine-scale features in a particular domain. One of the most prominent advantages of using these grids is the high efficiency for high-order methods. In this talk, we examine the viability of overlapping grids on mimetic operators, by solving representative PDEs problems using these operators on overlapping grids generated by Overture, while exploring different interpolation techniques on these grids (both implicitly and explicitly).

This research is supported by the Computational Science Research Center at San Diego State University.

#### **Repeated Measures Random Forest Algorithm**

#### **By: Peter Calhoun, Juanjuan Fan, and Richard Levine** Advisor: Juanjuan Fan

Nocturnal hypoglycemia is a common phenomenon among patients with diabetes and can lead to a broad range of adverse events and complications. Identifying factors associated with hypoglycemia can improve glucose control and patient care. We propose a repeated measures random forest (RMRF) algorithm that can handle nonlinear relationships and interactions and the correlated responses from patients evaluated over several Simulation results show our proposed algorithm nights. captures the informative variable more often than naïvely assuming independence. RMRF also outperforms standard random forest and extremely randomized trees algorithms that naïvely assume independence. We apply our method to analyze a diabetes study with 2,525 nights from 127 patients with type 1 diabetes. We find nocturnal hypoglycemia is associated with age, hbA1c, diabetes duration, bedtime BG, insulin on board, exercise, and daytime hypoglycemia.

This research is supported by the Computational Science Research Center at San Diego State University and the Department of Mathematics and Statistics at San Diego State University. SC16 Student Cluster Competition Challenge: Investigating the Reproducibility of Results for the ParConnect Application

**By: Gary R. Williams and Mary Thomas** Advisor: Mary Thomas

At SC16, the SCC teams participated in a new application area: the Reproducibility Challenge. In this poster we report on our efforts to reproduce results presented in a paper titled "A Parallel Connectivity Algorithm for de Bruijn Graphs in Metagenomic Applications," which shows that the parallel graph-based algorithm developed scales to over a thousand cores, and runs faster than traditional Breadth First Search algorithms. In general, using the smaller competition test data sets, we were able to reproduce some, but not all, of the reported results: we were unable to run the D1 data set on 128 cores and 2 GB/core memory as the paper suggested; our results did show similar timing trends for the different algorithm variations; we were able to observe the trend of communication dominating the computation time; and the AP and AP\_LB versions of our runs on smaller data sets only show a small time improvement in our graphs, which is similar but not exactly what was described within the paper. We believe that cluster architecture, required memory, network tuning, and number of processors available impacted our ability to exactly reproduce the results of the paper.

This research is supported by the President Leadership Fund with the Computational Science Research Center at San Diego State University.

#### Mimetic Methods on Unstructured Grids

**By: William Byrd and Jose Castillo** Advisor: Jose Castillo

Mimetic discretization methods are derived from discrete Divergence, Gradient and Curl Operators that satisfy, in the discrete sense, the same properties as their continuum counterparts . Methods for constructing high order mimetic Gradients and Divergences on rectangular grids have been developed by Castillo and Grone for structured staggered grids. To create Mimetic operators on unstructured triangular grids, we use an analogous approach. First we create mimetic operators on a grid of equilateral triangles, then we will extend their application to general triangles while preserving their mimetic conservation properties. Here we present preliminary results of this approach.

This research is supported by National Science Foundation funds (DUE-1259951), and the Computational Science Research Center at San Diego State University. Application of Extended Corresponding States Equation of State and Chemical Equilibrium Model for Carbon Sequestration

#### **By:** Alonso Navarro, Christopher Paolini, and Jose Castillo Advisor: Christopher Paolini

The capture and geologic sequestration of carbon dioxide has shown to be a promising method for reducing greenhouse gas emission from coal- and gas- driven power plans. In order to generate a robust design of capture and storage systems, an understanding of the thermophysical properties of H2O-CO2 mixtures is essential. A necessary approach to this is the evaluation of Equations of State (EoS) which can provide accurate thermophysical properties at conditions experienced in the location of geologic sequestration. In this work, EoS are being evaluated for pure and aqueous CO2 mixtures. The focus is on the extended corresponding states Soave-Redlich-Kwong EoS, which is expected to provide good accuracy at supercritical conditions needed to model the phase of injectant CO2. In parallel, an equilibrium model is being developed that calculates the chemical composition of supercritical CO2-H2O-NaCl mixtures in brine saturated reservoirs. The equilibrium model is based on the minimization of the Gibbs free energy through the method of augmented Lagrange Multipliers. As part of the equilibrium calculations, the extended Debye-Huckel equation is used to calculate the activity of the chemical species. The EoS and equilibrium models will be used to compute a multiphase equilibrium distribution of the CO2-H2O mixing zone.

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#### A Well Posed Approach to Modeling the Elastic Wave Equation using Mimetic Finite Differences

#### **By: Trevor Hawkins and Peter Blomgren** Advisor: Peter Blomgren

The energy method has been shown to produce well-posed solutions to hyperbolic initial value problems. This analysis has previously been completed for the first order elastic wave equation with a perfectly matched layer (PML) and its discrete numerical approximation using summation-by-parts finite difference operators. We extend this analysis of the first order elastic PML system to a different discretization scheme. Specifically, we implement a well-posed numerical model on the standard staggered grid using Castillo-Grone mimetic finite difference operators with strongly imposed boundary conditions.

This research is supported by the Computational Science Research Center at San Diego State University and the Department of Mathematics and Statistics at San Diego State University.

## Robust Statistical Methods for the Ensemble Kalman Filter for Data Assimilation

#### *By: Colette Smirniotis and Barbara Bailey Advisor: Barbara Bailey*

Data assimilation is the process of combining observations with the output from physics-based numerical models and is used for the purpose of updating and improving forecasts. Previous studies have found that for small domains on the order of a few kilometers, every observation impacted every state variable and the assimilation system exhibited sensitivity to observation error variance. Robust methods can be used when observations seem to come from a distribution for which the assumption of normality is suspect. Incorporation of robust statistical methods with the data assimilation framework into the model system can further improve the model accuracy. We present the results of the evaluation of the performance of robust methods for the Ensemble Kalman Filter for data assimilation.

This research is supported by the Computational Science Research Center at San Diego State University and the Department of Mathematics and Statistics at San Diego State University.

#### A Mirroring-Assisted Channel-RAID5 SSD for Safety-Critical Mobile Applications

#### **By: Wen Pan and Tao Xie** Advisor: Tao Xie

NAND flash memory based solid state drive (SSD) becomes an increasingly popular storage device for safety-critical mobile applications like a remote robotic surgery. However, manufacturers are aggressively pushing flash memory into smaller geometries and each memory cell has to store more bits, which lead to a higher bit error rate that exceeds the capacity of an ECC scheme. An uncorrectable error is more detrimental to a safety-critical mobile application where data loss could cause disasters. One natural approach to enhancing data reliability is to employ a data redundancy scheme at the channel-level of an SSD. Unfortunately, simply applying an existing RAID technique significantly degrades performance. In this paper, we first propose a new RAID5 architecture called CR5M (Channel-RAID 5 with mirroring) to alleviate the performance degradation problem. Next, an associated data reconstruction strategy called MCR (mirroring-assisted channel-level reconstruction) is developed to further shrink the window of vulnerability. Experimental results demonstrate that compared with CR5 (channel-RAID5) CR5M improves performance in terms of mean response time by up to 40.2\%. The results also show that compared with DOR, a traditional data reconstruction scheme, MCR on average improves data recovery speed by 7.5\% while delivering a similar performance during data reconstruction.

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