SEAS Undergraduate Student Affairs and Global Programs,
The Engineering Student Council, and
The Columbia Undergraduate Scholars Program present
the Fourth Annual

Undergraduate Research Symposium

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The Fu Foundation School of Engineering and Applied Science
1864–2014

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Student Research Posters

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Masih A. Babagoli, CC '18, Biochemistry

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Stephanie Michaels, SEAS'18, Biomedical Engineering

Comparative Study of Laser Scribing of SnO_2:F Thin Films Using Gaussian and Top-Hat Beams
Stephanie O'Gara, SEAS '16, Mechanical Engineering

Exploring Probabilistic, Context-Specific Models of Somatic Mutations in Human Cancer
Stephanie Rager, SEAS '19, Biomedical Engineering

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Stranger Danger: Pro-Social Behavior in Rats
Zoey Chopra, CC '18, Undecided

The Roundness of a Tool's Cutting Edge

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Supervising Faculty, Sponsor, and Location of Research
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Abstract

My research was in the field of manufacturing, specifically with cutting metals, such as Inconel 718, which is popularly used in the aerospace industry. As part of a larger project involving a hydraulic broaching machine, my goal was to determine the parameters needed to drag-finish the tools used in broaching. When broaching, it is important that the cutting edge of the tools is not completely sharp, as this leads to low impact resistance, rapid wear, and mechanical failure. Of course, the cutting edge must not be too blunt either, as then too great a force is needed to cut with it. In preparation for a later project investigating the ideal cutting edge of tools, my goal was to discover the parameters needed to round them to a certain degree on the OTEC drag-finishing machine.

I looked at how both time and the velocity of the rotating drum affected the process of rounding. After some initial experiments to determine what range of inputs I should use, the best way to position the tool in the machine and to get used to using the machines, I ran a total of nine tests, at three different velocities, measuring the radius of the cutting edge every five minutes using a NanoFocus machine. The main difficulty (and source of error) that I encountered was in measuring the radius. The NanoFocus machine can provide an average profile of the cutting edge, but there is no good method of quantitatively describing the profile for ease of comparison, given that so often the curve is irregular or the edge is dented or flawed. I also spent a lot of time ensuring that the roundness was consistent along the length of the edge.

From my experiment, I concluded that it is better to drag-finish tools at an average velocity for a longer period of time, rather than for shorter periods of time at higher speeds. This ensures that the radius is more regular.

Keywords
broaching, drag-finishing, cutting edge

Identifying the Nucleolar Function of Cockayne Syndrome Proteins

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Cockayne Syndrome (CS) is a rare autosomal recessive genetic disorder characterized by two complementation groups, A and B, which encode for the CSA and CSB protein, respectively. This premature aging disease has predominant clinical features including sunlight sensitivity, impaired development, and multisystem progressive degeneration like neurological abnormalities. It was found that wild-type CSB localizes to the nucleolus, but mutant protein is excluded. The aims of this research were to determine the regulatory components for CSB localization to the nucleolus and characterize the nucleolar stress response in CSB or CSA deficient cells. Computational analysis using NoD software found three putative nucleolar localization signals (NoLSs) in the full-length CSB protein. After transfecting HeLa cells with fluorescent plasmid containing candidate signals, it was determined by confocal microscopy and immunostaining that NoLS#1 (amino acids 302-341) and NoLS#2 (amino acids 1193-1243) targeted GFP to the nucleolus. Site-specific and deletion mutants were also created to determine critical amino acids. Within NoLS#1, amino acids 316, 317, 323, and 324 were found to be essential for nucleolar localization. Next, the cellular status of p53 activation, a key step in the hypothetical nucleolar stress pathway, was studied. CSB or CSA deficient cells expressed the highest levels of phosphorylated p53 after being irradiated with 6 J/m^2 and grown up for 4 hours. This optimal dose will be administered and the distribution of p53 and ribosomal proteins elucidated once establishing an effective cell fractionation methodology. This research introduces the potential role of the nucleolus in the pathological development of CS; further work must be conducted to characterize the nature of the nucleolar stress response and identify the critical proteins involved in this pathway.

Keywords

aging, nucleolus, stress, cockayne syndrome

Analysis of Star Diblock Copolymers Designed for Biomedical Applications

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Star polymers are a class of molecules that hold great promise as drug delivery vehicles due to their potential for delivering targeted and timed dosages for treating diseases such as cancer and rheumatoid arthritis. Careful study of these polymers is necessary to verify their ability to function properly and safely in physiological conditions. Therefore, we analyzed the behavior of two classes of star diblock copolymers, developed by IBM, which are the first of their kind to load and release hydrophobic drugs under different conditions. In the first class, designed to be degradable, the diblock arms are composed of a hydrophilic block of polyethylene glycol and a hydrophobic block of poly-δ-valerolactone attached to a caprolactone core. The second class's non-degradable polymers consist of a divinylbenzene core with arms of polystyrene and polymethacrylate, which has varied amounts of polyethylene glycol and tertiary amine pendant groups. The size and shape of these molecules over a range of pH values was investigated using small angle x-ray scattering. Preliminary analysis of the data showed that the polymers take on a globular shape. The data were then fitted to ideal geometric functions, which demonstrated that the polymers take on a "core-shell" shape in solution, with the hydrophobic blocks of the arms densely packing to create a spherical "core" and the hydrophilic blocks loosely creating a "shell." The degradable series of polymers, as expected, was more polydisperse (heterogeneous in size) than the non-degradable series. The more basic non-degradable polymers were found to expand in size with decreasing pH. This trend is likely due to repulsion between the tertiary amine groups, which become positively charged in acidic conditions. Overall, the ability of these polymers to change shape and size in response to pH will make them attractive candidates for tunable drug uptake and release.

Keywords

star polymers, drug delivery, scattering, tunable release

A Deep Observation of Gamma-ray Emission from Cassiopeia A using VERITAS

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Supernova remnants (SNRs) have long been considered the leading candidates for the accelerators of cosmic rays within the Galaxy through the process of diffusive shock acceleration. The connection between SNRs and cosmic rays is supported by the detection of high energy (HE; 100 MeV to 100 GeV) and very high energy (VHE; 100 GeV to 100 TeV) gamma rays from young and middle-aged SNRs. However, the interpretation of the gamma-ray observations is not unique. This is because gamma rays can be produced both by electrons through non-thermal Bremsstrahlung and inverse Compton scattering, and by protons through proton-proton collisions and subsequent neutral-pion decay. To disentangle and quantify the contributions of electrons and protons to the gamma-ray flux, it is necessary to measure precisely the spectra and morphology of SNRs over a broad range of gamma-ray energies. Cassiopeia A (Cas A) is one such young SNR (~350 years) which is bright in radio and X-rays. It has been detected as a bright point source in HE gamma rays by Fermi-LAT and in VHE gamma rays by HEGRA, MAGIC and VERITAS. Cas A has been observed with VERITAS for more than 60 hours, tripling the published exposure. The observations span 2007-2013, and half of the data were taken at large zenith angles to boost the effective area above few TeV. We will present the detailed spectral and morphological results from the complete dataset.

Keywords

Cassiopeia A, young supernova remnant, very high energy, spectrum, centroid

Structured Light Sheet Microscopy for High-speed, Volumetric Imaging

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Over the past decade, light sheet microscopy (LSM) has emerged as a promising volumetric (3D) imaging modality, particularly in the field of developmental biology and neuroscience. Swept confocally aligned planar excitation (SCAPE) microscopy is a novel LSM variant that permits the imaging of large fields of view at high speeds ($>$ 20 volumes/second) over a diverse set of samples, from freely crawling *Drosophila* larvae to in vivo mouse brain.

A major challenge in imaging thick samples is degradation of image quality due to light scattering caused by the sample’s tissue. Here, we present an implementation of SCAPE with HiLo, a type of structured LSM that reduces out of background components and improves contrast.

Although the implementation is still under development, SCAPE with HiLo does somewhat reduce out of background focus and improve optical sectioning (i.e producing clearer images in the deeper parts of the sample versus typical uniform illumination) in an ex vivo mouse brain of with a field of view of 934 μm x 252 μm x 895 μm (721 x 221 x 500 $voxels$). To improve the novel SCAPE with HiLo imaging method, further work is still needed to eliminate the introduced horizontal streaking and artifacts.

Keywords

Light Sheet Microscopy (LSM), volumetric (3D) imaging, Swept Confocally Aligned Planar Excitation (SCAPE), out-of-background focus, HiLo, uniform illumination

Spectrum Occupancy/Dynamic Range Measurements

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Supervising Faculty, Sponsor, and Location of Research
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Abstract

The phenomenal growth of the use of mobile wireless devices has resulted in a pressing spectrum scarcity. The hunger for more wireless bandwidth is only expected to further increase given new technologies like the "Internet of Things" where machine-to-machine or device-to device communications will put additional demands on the limited spectral resources beyond what mobile human users are consuming. Frequencies between about 700MHz and 6GHz are most desirable for mobile wireless terminals due to the nature of EM wave propagation, the availability of bandwidth at different carrier frequencies, and the practical size of antennas. As such, the electromagnetic spectrum is a finite resource and the solution for spectrum scarcity needs to be sought in a more efficient use of this scarce resource.

Attaining a good understanding of the different spectral band occupancy and power levels of the occupied bands is a pre-requisite to develop future wireless systems that can sense and react to the environment to utilize the under-utilized spectrum usage. The purpose of this research is to develop systematic methods and hardware to measure and evaluate the spectrum occupancy and power levels of the occupied bands over time.

Keywords

Internet of Things, spectrum scarcity, spectral resources, wireless systems, spectrum occupancy

Modified Coffee Rings for 1-D Conductivity

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Supervising Faculty, Sponsor, and Location of Research

Dr. Luz Martinez-Miranda, Andrew Blyskal, University of Maryland Energy Research Center

Abstract

We studied the coffee ring effect on 115nm x 20-50μm silver nanowires in isopropyl alcohol solution to determine the concentration with maximal flow velocity. We aim to investigate the 1-D conductivity of the coffee rings at their highest flow rate. Varying the nanowire concentration on several glass gratings of increasing depth, we observed two primary forces acting during the evaporation of a droplet of nanowire solution. We have found that the greatest effect of these capillary forces was on the deepest gratings that show a chimney-shaped phase diagram of flow velocity in comparison to the almost undifferentiated phase diagrams for shallower gratings. We are interested in finding the combination of nanowire concentration and grating depth to evidence the greatest flow velocity and in the future, to determine any significant increases in conductivity at the heterogeneous phase.

Keywords

silver nanowires, coffee ring effect, heterogeneous phase, transparent electrodes

Development of Fluorescent Variants of HIV

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

HIV/AIDS is a global pandemic with up to 35 million people living with HIV in the world. Treatment is now available to people with the disease which allows the disease to be suppressed and the immune system to rebound. However, the biggest impediment to HIV/AIDS cure remains the presence of a reservoir of infected immune cells located in various tissues which are latently infected and not expressing any HIV proteins on their cell surfaces. This summer, I designed and made six constructs of the HIV virus cloned with a Blue Fluorescent Protein (BFP) gene alongside one of the following three Internal Ribosome Entry Sites (IRES); Encelocardiomegalovirus (EMCV), Enterovirus 71(EV71) and the self-cleaving peptide F2A located on either side of the Nef construct. I used Gibson cloning to introduce them into the HIV genome. I sought to assess long term infection in humanized mice and ultimately the viral reservoir. I produced virus using mammalian HEK293Ts and tested the efficacy of infection from these virus constructs using flow cytomettry of cells infected by spinoculation. I then selected the construct which imposed the minimum fitness cost on the virus and lead to the least changes in its infection ability and Nef downregulation. I found that the construct with BFP followed by the IRES from EV71 had the minimal fitness cost on the virus.

Keywords

molecular biology, immunology, HIV/AIDS

Mechanosensor in Integrin Signaling: The emerging role of EGFR

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Supervising Faculty, Sponsor and Location of Research

Professor James C. Hone, Mentor Shuaimin Liu, Research Experience for Undergradute, Hone Group - Michael Sheetz Laboratory, Columbia University

Abstract

Although the epidermal growth factor receptor (EGFR) is known to interact with integrins in the processes of cellular spreading and motility, little is known about the actual role of EGFR. Previous studies from our laboratory have shown that in the early interactions of cells with rigid Arg-Gly-Asp (RGD) ligands, EGFR activity is needed for normal cell spreading and for the assembly of local contraction units that sense rigidity. EGFR inhibitors blocked local contractions and normal spreading in media lacking serum and soluble EGF. Here, we test the hypothesis that EGFR is mechanically activated by substrate stiffness through selectively modulating stiffness of submicron pillar arrays and we analyze the correlation between local contraction force and EGFR phosphorylation. To verify our hypotheses, we used submicron pillars of different stiffnesses as mechanical tools to study the effect of EGFR on cellular growth. On the one hand, our results suggested that wild-type cells plated on pillar arrays exert more contraction forces on these pillars than EGFR-inhibitor cells plated on similar arrays. Thus, EGFR is correlated with cellular rigidity sensing. On the other hand, we also showed that paxillin and phosphorylated EGFR have higher concentrations in the cellular regions plated on stiffer pillars. From these findings, we concluded that EGFR is a mechano-sensor with a higher level of activation on stiffer substrates.

Keywords

epidermal growth factor receptor, submicron pillars, contractile units, mechano-sensor, EGFR phosphorylation

Area-Efficient Hardware Design of a Tunable Digital Filter for Ultra-High Density Neural Recording Systems

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Supervising Faculty, Sponsor, and Location of Research
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Abstract
As microelectrode arrays (MEAs) with rapidly increasing channel densities are developed to investigate increasingly large ensembles of neurons, the challenges of processing the data in real time has scaled accordingly. For our target 256 x 256 channel recording system, the data rate of approximately 3 GB/s renders processing schemes considered efficient in conventional applications entirely infeasible for this device. Here, we propose a highly efficient and modular infinite-impulse response (IIR) filter design implemented on field-programmable gate arrays (FPGAs) with stringent chip area and processing latency constraints. Strategic optimization of tradeoffs in area, timing, and precision allow for the implementation, in inexpensive FPGAs, of a pipelined band-pass IIR filter with tunable cutoff frequencies for all channels on the device.

Keywords
IIR filter, microelectrode array, extracellular recording, high density, real-time

Modeling Fundamental Scattering Patterns

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Although nanotechnology is emerging as a solution to myriad global issues, relatively little is known about the atomic structure of materials at the nanoscale, or nanostructures, at present. The Billinge Group works to utilize comprehensive scattering techniques and advanced computing to "solve the nanostructure problem." To determine nanostructures experimentally, typically, powder diffraction data is collected, and then the related atomic arrangement is reconstructed. But what if we could do the opposite process? The aim of this project was to create a computational tool to model diffraction patterns of scattering objects, with the ultimate goal of being able to predict atomic structures from the power spectral density of any arbitrarily shaped object. Theoretically, plane waves incident on a particle will generate interference analogous to a single slit diffraction pattern. Therefore, by modeling the intensity of light transmission through any aperture, it was possible to predict particle scattering patterns. First, to ensure functionality of the script, we tested the output for many apertures of different dimensions by comparing the Fast Fourier Transform in Python to the analytic transform derived in *Diffraction Physics* by physicist John Cowley. Then, using image-processing packages in Python, we modified the function to take user-input images of aperture shapes and plot the corresponding power spectral density. The preliminary abilities of the program indicate that further development may lead to real-space object scattering models and eventually serve as a valuable tool to expedite the process of conceptualizing nanostructures.

Keywords

diffraction pattern, scattering object, fourier transform, python

Initiating and Characterizing Cartilage Damage under Physiologic Loading Conditions

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Osteoarthritis (OA) is a joint degenerative disease characterized by damage and loss of articular cartilage, a cushioning material on the joint. Despite the prominence of OA, promising treatments such as implantation of grown cartilage lack relevance for those who have yet to develop the disease. This study addresses the aforesaid population by focusing on preventative rather than curative measures of OA. By investigating the wear mechanism of OA, we aimed to identify a robust parameter of damage and to develop good preventative measures against advancement of OA. We tested two hypotheses to clarify our understanding of the OA mechanism: i) friction coefficient alone is a poor indicator of cartilage damage; ii) fatigue wear with delamination is the chief wear mechanism of OA.
To analyze the friction response of cartilage under different physiologic loading configurations, 12 immature bovine knee joints were harvested and prepared for experimentation. To induce damage to cartilage, both the choice of boundary lubricant and the choice of contacting load material were considered. Each cartilage explant was submerged in a culture medium of either synovial fluid (SF) or saline. Further, each explant was subjected to migrating sliding motion with glass lens or cartilage contact surface.

Significantly, our data showed that friction coefficient undergoes a temporal evolution during a damage event. The results elucidated the source of disagreement regarding friction coefficient between prior research and our preliminary data. Friction coefficient was revealed a good measure of damage only if recorded when damage occurred. As hypothesized, our results strongly suggested fatigue wear to be the prevailing mechanism of initial cartilage damage. We saw visible delamination of the middle zone in our samples, characteristic of fatigue damage. This study encourages further investigation into the contributors of cartilage wear to better explain the goings-on in the joint during OA progression. Building a modeling framework for cartilage wear mechanics is desirable for simulating a wider range of loading conditions.

Keyword

osteoarthritis, articular cartilage, friction coefficient, physiologic loading configurations, fatigue wear mechanism

Screening of Vitamin D Derivatives Using a Yeast Two Hybrid System

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Supervising Faculty, Sponsor, and Location of Research
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Abstract
The yeast two hybrid (Y2H) system has been shown to be an important and valuable tool for investigating protein-protein interactions in a high-throughput manner. The aim of this study is to use the yeast *Saccharomyces cerevisiae*, as a heterologous host for discovery and production of biologically active vitamin D derivatives, such as 1α,25-dihydroxyvitamin D_3 (calcitriol). The selection of yeast cells that produce calcitriol and other vitamin D derivatives can be achieved with the Y2H system. Previously, a Y2H system that successfully screened for vitamin D has been reported, in which a lacZ reporter gene and GAL4 transcription factors were used. For our Y2H system, one integration plasmid containing the LexA DNA binding domain fused to the vitamin D receptor ligand binding domain (LexA-VDR) and an expression plasmid containing B42 activation domain fused to the retinoid X receptor β ligand binding domain (B42-RXRβ) were constructed, both located downstream of a GAL1 promoter. The LexA DNA binding domain and B42 activation domain allow compatibility with Gal activation of the cytochrome P450 hydroxylating enzymes. We hypothesized that the vitamin D-dependent heterodimerization of the VDR-LBD and the RXRβ-LBD will induce transcription of the reporter gene. Two different reporter genes, HIS3 and lacZ, were placed downstream of a minimal GAL1 promoter and multiple LexA operons. The HIS3 gene allows for selection of the cells of interest rather than screening, which can be more work-intensive. We demonstrated a 7-fold difference in optical density between the cultures with 100 nM calcitriol and no calcitriol. In addition, we demonstrated that the two hybrid system was at least 10 times more sensitive to calcitriol than other vitamin D derivatives, including calcidiol, calcipotriol, and vitamin D_3, using a beta-galactosidase assay. These results show promise in our yeast two hybrid strain's ability to be selected for calcitriol production. We are currently working on heterologously expressing in the same strain 25-hydroxylase (CYP2R1) and 1α-hydroxylase (CYP27B1), mammalian enzymes for calcitriol production from vitamin D_3, and using the Y2H system to optimize production of active vitamin D derivatives.

Keywords
yeast two hybrid system, vitamin D, Saccharomyces cerevisiae, screening

Recommendations for Items Using Web Crawl Techniques, Tag Cluster Data, Cosine Similarity Calculation, and Wikipedia Title Matching

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Asia Trend Map, a unique website displaying thousands of Japanese and international cartoons, comics, books, games, and more. Sponsored by the Ministry of Economy, Trade, and Industry in Japan, its aim is to visualize the current and 6-months-ahead popularity of these titles. The goal of this project is to create more engaging content for users on the Asia Trend Map website. In particular, recommendations are a good way to link to different content in our site, and for users to explore new titles. To do this, I investigated collaborative filtering, a technique used to make automatic predictions about the interests of a user by collecting preferences. However, I eventually used web crawl techniques to obtain tag data for several thousand titles from Anikore, a popular anime website in Japan. Then, I performed a cosine similarity calculation to identify the four most similar titles corresponding to each title. Then, I used a Google Search Query to match Wikipedia titles to the titles stored on the back end of Asia Trend Map. Finally, I presented the recommended titles on the website.

After comparing the accuracy and speed of this approach on a dataset of over 8000 tags, I concluded that tag by item clustering proved to be more accurate than other alternative approaches, in about the same amount of time. The accuracy was also confirmed through several human tests as well.

Keywords

data mining, collaborative filtering, item clustering, recommendations

Enabling 5/Next-G Wireless Communications with Energy-Efficient Rapid Spectrum Sensors

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Supervising Faculty, Sponsor, and Location of Research
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Abstract
Wireless systems have become an essential part of every sector of the global economy. In addition to the existing commercial systems including mobile cellular, WiFi communications and global positioning system, emerging systems like video over wireless, Internet of Things, and machine-to-machine communications are expected to increase the mobile wireless data traffic by several orders of magnitude over the coming decades while the natural resources like energy and radio spectrum remain scarce. If the consumer demand for instantaneous, over the air access to large volume of content continues to grow at its current rate in the US, a 500MHz to 1GHz spectrum deficit is expected in the near to long term.

Cognitive radio is a paradigm proposed to overcome the existing challenge of underutilized spectrum. Smart devices opportunistically use the underutilized spectrum and will need spectrum sensing for incumbent detection and interferer avoidance. Integrated interference detectors need to be fast, wideband and energy efficient. Compressed sensing as a blind sub-Nyquist sampling method has the potential to deliver this energy efficient and rapid interferer detection over a wideband spectrum. Compressed sensing allows users to gather data and information about the spectrum by sampling at a rate defined by information content rather than instantaneous bandwidth of the spectrum.

We demonstrate a rapid interferer detector exploiting compressed sampling (CS) with a quadrature analog-to-information converter (QAIC) . Our architecture is two orders of magnitude more energy efficient compared to traditional spectrum scanners and one order of magnitude more energy efficient compared to existing CS spectrum sensors. To scan a wideband 1GHz frequency span with a 20MHz resolution bandwidth, it offers 50x faster scan time compared to traditional sweeping spectrum scanners and 6.3x compressed aggregate sampling rate compared to traditional concurrent Nyquist rate spectrum scanners.

Keywords
cognitive radio, spectrum sensing, rapid interferer detection, compressed sampling

Hungry Hearts: Histone Deacetylase Regulation of Autophagy

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Supervising Faculty, Sponsor, and Location of Research
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Abstract
The general medical category of "heart disease" includes many health conditions including hypertension (high blood pressure), myocardial infarction, and heart failure. Collectively, these conditions and many others that fall under heart disease are the leading cause of death in the United States of America. Cardiology research now focuses on mechanisms that result in these diseases and ways to limit, stop, or even reverse their damaging effects. The research conducted in this study hinged on three many key areas of research in the field. The first area is pathological cardiac hypertrophy, which is a type of growth the heart undergoes due to prolonged sickness or stress on the heart system. This form of growth differs from physiological hypertrophy that occurs after exercise or pregnancy in that prolonged pathological growth ultimately results in heart failure. Previous experiments have linked pathological hypertrophy to a second area of research – autophagy, which is a process that cells undergo to recycle existing organelles into new material for cell growth. Autophagy is a key process in the growth of heart cells since these cells are unable to multiply through traditional processes of mitosis. Finally, autophagy has also been linked to histone deacetylases (HDACs), which are proteins in the cell that regulate gene expression.

Therefore, the aim of this study was to take these three branches of cardiology research and see the correlation amongst them in different cell environments. Using synthetic RNA (siRNA), various HDACs were "knocked-down" in Neonatal Rat Ventricular Myocytes (NRVMs). Then the levels of autophagic flux and therefore hypertrophy were measured as a result of these HDAC knockdowns. Although the data collected is not yet conclusive, the preliminary findings indicate that the HDACs (organized into two pre-established classes) *do* have an effect on autophagy in heart cells. These findings point to the conclusion that in the future HDACs could be (further) used to regulate heart growth and to prevent heart disease in patients.

Keywords
Histone deacetylase (HDACs), autophagy, hypertrophy, pathological cardiac hypertrophy, heart disease

Parameter Estimation Analysis of PRANDTL 2 Flight Data

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Conventional aircraft make use of the elliptical lift distribution (spanload) for wing loading. However, it may be demonstrated that the bell-shaped spanload is the most efficient distribution for a given amount of wing structure, with theoretical induced drag reduction of 11%. A consequence of this spanload is induced thrust at an aircraft's wingtips and, as a result, the phenomenon of proverse yaw—that is, yaw in the direction of the turn induced by roll.

The PRANDTL 2 aircraft is an experimental glider in NASA Armstrong Flight Research Center's PRANDTL-D program designed to make use of the bell-shaped spanload. During the summer of 2015, students performed several data collection flights with this aircraft and observed the vehicle's ability to achieve proverse yaw. Data from these flights was then analyzed in order to obtain the control and stability derivatives (c/s derivatives) to characterize the aircraft. Specifically, positive values for the yawing moment due to aileron deflection coefficient (Cnda) would indicate the existence of proverse yaw.

Finding the c/s derivatives required the use of parameter estimation. The team used NASA AFRC's pEst (Parameter Estimation) program in order to relate the pilot input during a flight maneuver with the response of the aircraft. By iteratively approximating the c/s derivatives, pEst recreates the time history of a flight and obtains reasonable estimates for these coefficients. After a series of data preparation procedures, students used pEst to determine the aerodynamic parameters of the glider—in particular, positive values of Cnda were determined, in agreement with theoretical and prior experimental findings. These results provide further information on PRANDTL 2's novel wing design, which could eventually lead to dramatic improvements in aircraft design and efficiency.

Keywords

bell-shaped lift distribution, proverse yaw, parameter estimation, pitch/roll doublet

Development of an Inexpensive Telescope System for Very High Energy Astronomy: EL CHEAPO

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Over the past ten years, the field of very high energy (VHE) astrophysics has developed dramatically, with the number of known sources jumping from 30 in 2005 to over 160 today, as reported by TeVCat. The Cherenkov Telescope Array (CTA) is the next major international project in the field, scheduled for first observations in 2018. However, as with any telescope, CTA will have a finite field of view and limited number of observing hours per year. The ultimate goal of this project is to demonstrate that it is possible to build a relatively low cost (~$50,000) telescope, complimentary to the capabilities of CTA, capable of studying VHE (>1TeV) gamma rays. Over the course of the summer the mounting and pointing systems for a prototype imaging atmospheric Cherenkov telescope will be completed. This will involve both hardware additions to the system and the development of a software program to control pointing and tracking. Ultimately, the prototype telescope will be installed at the Goddard Geophysical and Astronomical Observatory, and will be integrated with components developed by external collaborators.

Keywords

astrophysics, gamma-ray, instrumentation, telescope

Determining the Effectiveness of the Menikoff-Kober Porosity Model on Lunar Crater Formation

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

The lunar surface is composed primarily of basalt-heavy regolith material which has been rendered porous by constant meteor bombardment and surface mixing. Porosity is a quality of regolith material that has proven difficult to model even on the most advanced hydrocodes, as representing a porous material is complicated by resolution issues, as well as the computational difficulty of implementing multi-material cells within a mesh. However, by treating porosity as a bulk property averaged over a large enough sample, it is possible to achieve good agreement between experiment and simulation without simulating the exact porous nature of a material. To examine a particular model for shock wave propagation through the lunar regolith, we conducted hydrocode simulations on supercomputers at Los Alamos National Laboratory.

Comparing these high performance computing simulations to experimental data taken from shock wave experiments conducted with lunar simulant material (JSC-1A), we observed good agreement, indicating that the Menikoff-Kober model can give good predictions of shock wave propagation through porous media. However, problems plagued the hydrocode simulations. To accurately simulate these high velocity flyer plate experiments, the thermodynamic equations of state for all materials involved must be as accurate as possible, and we observed poor compatibility of the hydrocodes with the tabular equations of state maintained by the laboratory. In addition, thermodynamic considerations have suggested that an extra term added to the Helmholtz free energy of a porous material could improve simulations by giving the code a more robust treatment of porosity energetics.

Keywords

thermodynamics, high-performance computing, planetary science, hydrocodes

Evaluating the Monetary Health Benefit of the Current Citi Bike System and the Impact of Station Location in Areas of Different Socioeconomic Status on the Health Benefit

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Citi Bike – NYC's bikeshare system – was established in May 2013 and is currently the largest bikeshare program in North America (approximately 24,000 rides/day). However, there is little available literature on the health impacts of not only the current system but also its planned expansion. We had two objectives: 1) to estimate Citi Bike's current annual monetary health benefit and 2) to investigate how station location in areas of different socioeconomic status (SES) would affect the health benefit. A potential concern is that stations in lower SES areas are used less frequently. However, individuals in these areas have higher chronic disease and mortality rates that could benefit relatively more from increased physical activity. We used the WHO's Health Economic Assessment Tool (HEAT), which calculates and monetizes reductions in mortality due to increased physical activity. From HEAT, we estimated the health benefit of the current Citi Bike system to be approximately $46,000,000 per year. Secondly, we found that out of all census tracts containing newly planned stations, the highest and lowest poverty levels were 58.1% and 2.0%, respectively. Using a NYC DOHMH report containing the relationship between census tract poverty levels and mortality rates, we determined that the mortality rate in the lowest SES census tract was 1.7 times that of the wealthiest tract. Again using HEAT, we demonstrated that an equivalent health benefit – from averted deaths - would be obtained from new bike stations in both of these tracts even if rides decreased by much as 1.7 times for the new station in the lowest SES tract. Our findings underscore the immense health benefit from NYC's bikeshare and support establishment and promotion of new bike stations in lower socioeconomic areas.

Keywords

Citi Bike, bikeshare system, HEAT model, socioeconomic status, mortality rate

Automated Detection of Foot-Chases in Police Body-worn Video (BWV)

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Abstract

In order to provide a comprehensive understanding of police-public interactions, the Los Angeles Police Department (LAPD) intends to utilize *Body-worn Video* (BWV) collected from cameras fastened to their officers. BWV provides a novel means to collect fine-grained information about police-public interactions. The purpose of this project is to identify specific features from videos, in particular foot-chases, using machine-learning algorithms.

Our proposed algorithm uses semi-supervised methods such as the detection of point-features and their classification via support-vector machines. We partition our feature-set matrix into three parts (training, test and k-Means usage). After the k-Means algorithm generates an ideal number of clusters (our parameter testing showed k=500 was optimal), we apply a linear SVM to classify the histograms of the remaining videos and report results. Our training dataset consists of 100 training videos (20 foot-chase and 80 non-foot-chase) and a test dataset of 60 LAPD videos (4 foot-chase and 56 non-foot-chase).

We achieved results of 91.67% testing accuracy with 5 false positives and 0 false negatives. From this data, we can conclude that this method to evaluate police videos returns strong results. Greater robustness could be ensured by further testing on dataset swith varying proportions of foot-chase to non-foot-chase videos.

Keywords

Image processing, video processing, police body-worn video, bag-of-intrinsic-words, Support Vector Machine classification

Going Full Circle- From Wastewater to Biodegradable Plastic

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

The project aimed to address the problem of petroleum-based plastics that are difficult to recycle and they not biodegrade, hence severely polluting our oceans and natural environment. In parallel, the research investigated a new approach to wastewater treatment by examining the possibilities of using it as a resource generator. The project sought to produce biodegradable plastics using wastewater from a graphic board factory, at pilot scale. These polymers, polyhyroxyalkanoate or PHAs, are accumulated within the cells of certain types of bacteria as a carbon storage compound when there is a deficiency of either external nutrients or proteins within the cell required for their reproduction.

The core objective was to optimize this process at the factory using findings from previous studies at lab-scale. A critical component was maximizing percentage of polymer accumulated within the cell to improve efficiency of the final extraction, which would significantly reduce costs. This study attempted to identify methods to characterize the pilot process and assess its effectiveness. A related question was how the errors (systemic and human) could be quantified to determine reliability of the final measurement. Samples collected from different stages of the PHA production process were esterified and the monomers extracted to be analyzed using gas chromatography. Information regarding percentage of PHA was obtained over the cycle of enrichment and accumulation. This enabled the creation of a feedback loop with the design and operation of the pilot, informing future experimentation with the set-up. Data indicated a decline in effectiveness of the accumulation after x hours, which may be explained by the growth of a large side population and/or an increased amount of dead biomass. Key bottlenecks in the pilot scale process were examined.

Keywords

biodegradable plastic, wastewater, resource recovery, pilot-scale, biotechnology

Understanding the Amino Acid Requirements of a Simple Transmembrane Oncoprotein

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Understanding the mechanism of tumor virus action that results in tumor growth would provide critical insight into carcinogenesis, leading to advances in cancer diagnosis and treatment. However, like most proteins, most oncoproteins encoded by tumor viruses are very long sequences of amino acids, inhibiting our ability to understand protein shape and function. In order to gain mechanistic insight into tumor virus action, we studied a small oncoprotein, E5, a 44-amino acid protein that constitutively activates the platelet derived growth factor (PDGFβ) receptor via phosphorylation, causing cell growth transformation. Previously, the DiMaio lab showed that 26-amino acid artificial transmembrane proteins consisting only of the amino acids leucine and isoleucine activate the PDGFβ receptor and transform cells, just as E5 does. Through complete mutagenesis of these proteins, the DiMaio lab identified that a protein, "M3", consisting solely of leucines except for a single isoleucine at position 13 had transforming activity.

The primary question we addressed was if proteins simpler than M3 would behave in the same way as E5. We hypothesized that these ultra-simple proteins— that look nothing like the original E5 protein— would not cause cell growth transformation. In order to test this, we constructed a total of 18 simple transmembrane proteins, with each protein consisting of leucines with a distinct amino acid at position 13, to identify specific amino acid requirements for transforming activity. Preliminary results show that Asparagine, Serine, and Valine at position 13 confer transforming ability. We hope to discover "rules" for transmembrane interactions from PDGFβ receptor interactions with simple proteins. Using these rules, we can dictate how to activate or inhibit PDGFβ receptor, leading to great strides in cancer patient diagnosis and treatment.

Keywords

cancer, oncoviruses, E5, genetics, cellular biology

Measuring "ProG"ress: Characterization of Affinity Improved Protein G Variants

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Supervising Faculty, Sponsor, and Location of Research
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Abstract
Antibody-drug conjugates (ADC) are a promising class of biopharmaceutical drugs that link the targeting abilities of an antibody with the therapeutic effects of a payload to allow the targeted delivery of highly potent treatments. This targeting mechanism has made ADCs a popular platform for the development of anticancer drugs. ADCs can be created using full-length antibodies or shorter antibody F_{ab} fragments. For large-scale production purposes, F_{ab} fragments are more appealing due to their lack of glycosylation and ability to be produced in prokaryotic expression systems.

Protein G is an Immunoglobulin Binding Protein (IBP) expressed in group C and G of *Streptococcus* bacteria commonly used in production as a antibody purification reagent. It possesses binding affinities for both the F_c and F_{ab} portions of antibodies, though at differing strengths. While Protein G strongly binds the Fc region of the antibody with a $K_D \sim 10$ nM, its binding for the F_{ab} region is significantly weaker with a K_D in the low μM range. This weak affinity for F_{ab} limits the range of Protein G's applications for F_{ab} based drug-antibody conjugates.

Phage display methods provide a means to quickly select new Protein G variants that exhibit strong binding to F_{ab}. Two variants, ProG.A1 and ProG.A1.N13A, have been previously identified by the Kassiakoff lab at the University of Chicago as improved F_{ab} binding Protein G variants through phage display. Variant ProG.A1.N13A is distinguished from its counterpart by an additional engineered N13A mutation that confers base resistance and allows for more thorough and economic cleaning in place procedures using high pH buffers. Both Protein G variants express readily in *E.Coli* and are purified from cell lysate over a Ni-NTA column (via engineered His6 tag). Though the proteins exhibit minimal aggregation and couple readily to resin via iodoacetyl chemistry, improved binding ability for F_{ab} was not observed when the Protein G variants were coupled to resin or when they were measured "unbound" via Surface Plasmon Resonance.

Keywords:
antibody drug conjugates, protein G, protein engineering, phage display, purification

Imaging of X-point turbulence in Alcator C-Mod

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

A nearly tangential view of the lower X-point region of Alcator C-Mod has been coupled to a high-speed camera filtered for D-alpha line emission. Recording at ~400,000 frames per second, the system detects filaments propagating in the private flux region that are approximately aligned with the local magnetic field. This behavior appears similar to what has recently been observed in the MAST tokamak [1]. Turbulence and transport into the private flux region is potentially important. It may be a mechanism to spread heat across field lines and reduce peak heat fluxes on divertor targets. It may also explain how transport-driven flows seen in the high-field side scrape-off layer [2] are accommodated, being otherwise too large compared to the particle flux arriving at the inner divertor target plates. The dynamics of these filaments are analyzed, as is the rate at which they are generated. Correlation analysis is used to determine the speed and trajectories of the filaments. Radial speeds of ~1 km/s are found. Clear changes are observed in the X-point-region fluctuations at the L-to-H-mode transition.

Keywords

nuclear fusion, plasma physics, tokamak, plasma turbulence

What is Ordered Mesoporous Silica?

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Supervising Faculty, Sponsor, Location of Research

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Abstract

Ordered mesoporous silica (OMS) is a versatile nano-carrier, having applications ranging from chemical catalysis to drug delivery. OMS is made of nano-sized, hexagonal crystals that have an intricate honeycomb structure of cylindrical pores. To the naked eye, these crystals look like powdered sugar. But, for example, when loaded with anti-cancer medication and tagged to attack specific targets, OMS particles act like Trojan horses, stealthily releasing cytotoxic agents inside unsuspecting cancer cells. OMS is unique in its biocompatibility, high surface area allowing for subsequently high drug loading, and ability to target cancer cells, thus sparing the healthy cells that chemotherapy normally destroys. OMS is therefore one example of nanotechnology in medicine that represents a paradigm shift from managing cancer to actually curing cancer.

Keywords

nanotechnology, materials, porous, catalysis

Role of Top1mt in Ribonucleotide Removal from Mitochondrial DNA

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Topoisomerases are ubiquitous enzymes that modulate the topology of the DNA double helix during replication and transcription. Of the six topoisomerase enzymes in human, only one is completely dedicated to the mitochondria. Absence of mitochondrial topoisomerase I (Top1mt) reduces the rate of mitochondrial DNA (mtDNA) recovery after DNA damage. Recent studies have shown that ribonucleotides are the most frequently mis-incorporated non-canonical nucleotides during replication and these mis-incorporations can lead to significant genome instability. Nuclear topoisomerase I has been implicated as a secondary pathway to ribonucleotide removal, while the primary repair pathway depends on RNase H2. Since RNase H2 is not present in the mitochondria, Top1mt might be implicated in the removal of ribonucleotides from mtDNA. To determine whether Top1mt is involved in ribonucleotide removal from mtDNA, we isolated the mtDNA from murine embryonic fibroblasts (MEF) generated from Top1mt knockout mice. We performed alkaline hydrolysis on the isolated mtDNA by treating the DNA with 2.5M KOH to selectively disrupt the phosphodiester bonds at ribonucleotide sites. The sample is then neutralized and run on an agarose gel to visualize the size of the resulting DNA fragments. The mtDNA from Top1mt knockout MEF contained more ribonucleotides than the mtDNA from the wild-type MEF cells. MtDNA from tissues extracted from Top1mt knockout mice showed similar results. Next, we generated Top1mt knockout human cancer cell lines using CRISPR technology, which targeted exon 6 of the Top1mt gene. Alkaline hydrolysis of the mtDNA from the Top1mt knockout human cancer cell lines confirmed that lack of Top1mt leads to accumulation of ribonucleotides in mtDNA. These findings implicate Top1mt in the removal of ribonucleotides from mtDNA.

Keywords

topoisomerase I, mitochondria DNA, ribonucleotide

Comparative Study of Laser Scribing of SnO_2:F Thin Films Using Gaussian and Top-Hat Beams

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Laser scribing is a common method used for manufacturing large-scale solar cells to increase cell efficiency by subdividing large cells into small mini-modules connected in series, decreasing the current produced and therefore reducing the ohmic losses. Introducing large temperature gradients causes thermal expansion and subsequently thermally induced stresses, and these stresses can be used to cause mechanical fracture and material removal. Gaussian beams, which are commonly used in existing scribing practice, have high energy intensity in the center of the beam resulting in unwanted substrate damage as well as excess energy toward the edge of the beam spot, contributing to the formation of a heat affected zone and partial melting also resulting in large sidewall taper and residual material. The top-hat distribution, having a much more rapid decrease in intensity at the spot edges and more uniform intensity throughout the, greatly reduces the likelihood of melting or partial removal on the spot edges, as well as the risk of damage to the glass substrate. However, little work has been done to quantify the differences in the resulting scribe quality of these laser beam intensity distributions. In this study, experiments were carried out on 400 nm thick SnO2:F TCO layer irradiated from the glass side using a 1064 nm Nd:YAG laser with both Gaussian and top-hat intensity distributions. Samples were processed using pulse energies ranging from 5μJ to 30μJ. Pulse repetition rates of 10 kHzwere used. Scribe geometry was observed using AFM scans and SEM images. Possible negative effects such as delamination and crack formation resulting from abrupt intensity changes are investigated. A coupled thermo-mechanical finite element model is used to analyze the spatial temperature and stress distributions within the film during the scribing process. Our results find that even when melting does occur for the top-hat distribution the taper-angle, scribe depth, and overall uniformity is improved over Gaussian samples.

Keywords

Laser scribing, solar cells, finite element analysis, SnO_2*:F*

Exploring Probabilistic, Context-Specific Models of Somatic Mutations in Human Cancer

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Somatic mutations in cancer cells are caused by intrinsic (e.g. methylation/deamination) and extrinsic (e.g. DNA binding molecules) mutagenesis factors. Many mutagenic processes are context-specific– mutational probabilities are determined by the type of mutagenesis and nucleic acid sequence context. While recent findings have uncovered some of these context-dependent mutational patterns, much remains unknown about the process of mutagenesis in cancer and how to separate selection from this background mutational process. By analyzing mutations recorded in the Catalogue of Somatic Mutations in Human Cancer (COSMIC), we derive context-specific probabilistic models describing the mutagenic process. Missense mutations alter the amino acid sequence, potentially affecting cellular fitness, and are therefore subject to selection pressure. Thus, we purposefully differentiate synonymous mutations from nonsynonymous mutations. We assume that synonymous mutations have no effect on fitness. The models we derive, along with four tools we have developed to utilize them (viewing models, comparing models, mutating a gene according to a model, and identifying the underlying mutagenesis process given contextualized mutations), are implemented into an openly accessible dynamic web server. We hope that our work will elucidate the poorly understood process of mutagenesis in human cancer by providing researchers and clinicians with the intuitive tools to explore the implications of mutational patterns in cancer with regards to effected proteins, mutagens, and factors that give cancer cells a selective growth advantage.

Keywords

context-specific cancer mutations, mutagenesis, computational biology, probabilistic models

Chemical Vapor Deposition of Graphene on Nickel Substrates

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

The experimental objectives are to determine favorable conditions for growing monolayer graphene via chemical vapor deposition (CVD) on nickel (Ni) substrates for future automotive, aircraft, and body armor applications. Graphene films were grown on 25 μm polycrystalline nickel foil in a 10 cm CVD furnace at temperatures from 900 to 1000 deg C. Micro-Raman Mapping was used to characterize the graphene films. Raman Spectroscopy shows that the majority of the samples were covered in multilayer graphene, with some monolayer and bilayer patches. Comparing optical images to Raman maps indicates that darker patches on the nickel foils have more layers of graphene. Growth parameters such as cooling rate, carbon concentration, growth time, temperature, and pressure were adjusted to try to decrease the amount of multilayer graphene (3 or more layers). The best growth showed 36% coverage of monolayer and bilayer and the rest multilayer graphene. Future experiments will involve CVD growth on Ni micro-lattices and single crystal Ni alloy. It is anticipated from literature that the thickness uniformity will increase for growth on single crystal Ni.

Keywords

graphene, chemical vapor deposition, nickel catalyst, Raman spectroscopy, microscopy

Impacts of Water Deficit on Groundwater Depletion

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Drought occurs during periods of water deficit, when variability in precipitation and water demand causes severe constraints on surface and ground water stores. Commonly used global and national drought indicators such as the Palmer Drought severity index, however, do not connect water demand patterns to the potential deficit that occurs during drought. In contrast, demand sensitive drought indicators measure the deficit between water supply and demand as it relates to human requirements across the contiguous United States. Over the past fifty years, groundwater levels in deep aquifers have declined across the country; this depletion has not only caused socioeconomic drought, but has also diminished defense against future drought. The following analysis studies the relationship between groundwater levels and demand sensitive drought index values on a county scale across the United States. First, groundwater level change data from 1950 to 2009 was interpolated to create a time series with one value for each county within the contiguous United States. The resulting time series of groundwater and drought data was correlated in two-sided Pearson and Kendall correlations and analyzed. For a composite analysis, the drought data was separated into dry, neutral, and wet phases; the average groundwater level change for each corresponding drought phase was calculated. The analysis reveals significant trends between drought occurrence and decreases in groundwater levels in the central United States; as water deficits increase, groundwater levels decrease. The analysis also reveals significant, positive correlations between groundwater and drought in parts of Utah, Colorado, and New Mexico. This unusual trend could be attributed to a variety of factors, but further analysis is needed to ascertain the cause.

Keywords

groundwater depletion, drought, correlation, demand sensitive drought index

A Correlational Neural Network Model

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Supervising Faculty, Sponsor, and Location of Research
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Abstract
Current neural network models are fixed after the training phase; therefore generalization to real-world situations is achieved by attempting to train on every possible input, which is unrealistic. In fact, such an extensive training set may not even be available in most cases. A network could instead use prior knowledge based on the statistics of its expected output to perform useful computations for a much broader range of inputs, without the need of a training period. Here we demonstrate the use of output autocorrelation as such a statistical target, and successfully apply this novel algorithm to the problem of speech denoising.

Keywords
neural networks, deep learning, artificial intelligence, speech processing

Stranger Danger: Pro-Social Behavior in Rats

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Supervising Faculty, Sponsor, and Location of Research

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Abstract

Empathy and pro-social behavior are characteristics we may often take for granted, at a closer look, these characteristics may be defining as to who we are as humans, explaining our constructs of society and notions of family and friendships. Recent research has shown that our empathetic response, which occurs when observing others in pain, is in fact correlated to the same neural pathway activated when we ourselves feel pain—by our very brain chemistry, we are naturally pro-social creatures of the environment. And yet, not all humans, or other organisms, are equally pro-social—we aim to understand why. Our research hopes to test the differentiating factors amongst different organisms' pro-sociality from both a behavioral and neurological basis, using rats as our model organism, and then expand this research to humans. We first did behavioral assays on Sprague-Dawley and Long-Evans rats, employing both stranger and cagemate conditions. In these hour-long tests, a Sprague-Dawley rat would be free, and either a cagemate Sprague-Dawley or stranger Long-Evans trapped within a restrainer that the free rat could open within an hour, if so desired. Using EthoVision, we tracked rat movements in both conditions, trying to find pro-social and anti-social patterns of behavior in both conditions.

The neurological aspect of the research came immediately after our third day of testing, when the free rat would undergo perfusion, such that its brain tissue could be sliced and stained. The tissue was stained with both oxytocin and c-Fos, the former to test correlation between oxytocin and pro-sociality, and the latter to test sites of neuronal activity. The tissue was then analyzed under microscope for observation of staining. Behaviorally, free rats in the cagemate condition appeared more stressed, indicated via greater average velocities for the hour of testing, more time spent latent to the restrainer, and greater proximity to the restrainer than in the stranger condition. Neurologically, we have only just started analyzing stained tissue and so cannot make any final predictions, but at first glance, there appears to be greater neuronal activity in the anterior cingulate cortex of free rats in the cagemate condition relative to the stranger condition. We have yet to conclude any concrete findings in our research. However, we can predict that the anterior cingulate cortex plays a role in pro-social behavior. Further data must be collected before further predictions and conclusions can be solidified.

Keywords

pro-social, behavior, empathy, neuroscience, anterior cingulate cortex

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