Poster Session Abstracts

Using Machine Learning to Classify Trees
Mohammad Arbab
Mentors: Mory Gharib and Julian Humml

As climates change to become warmer and drier, forest fires are becoming substantially more frequent. Utilizing the diverse applications of machine learning, this project has the objective of applying a deep learning model to a drone to classify trees and theoretically the type of tree to predict the path of forest fires. However, this project is mainly focused on whether or not a deep learning model can successfully do binary classification of trees. In order to achieve this, we're attempting to use an existing model to do transfer learning and image segmentation to isolate the subjects of the image. We're then using live video to apply this segmentation, where new and unique images will be shown to the model and it will create an inference. There are various factors that play a role in a learning model's performance such as dataset size, hyperparameters, weight decay, and linear layers. Because of this, we haven’t had a model that works yet, but one can be trained to do so with a sufficient dataset and possibly be able to identify species of trees in the long run. At the present stage, we are working on incorporating a camera for this image pipeline.

Interaction-aware Trajectory Planning Using Linear Quadratic Regulator
Nishka Arora
Mentors: Daniela Rus, Xiao Li, Johnson Wang, and Yutong Ban

When we drive, the past behavior of vehicles surrounding us helps us forecast their future interaction with our vehicle. For an autonomous vehicle (AV), predicting the behavior of other road agents and planning around these predictions is a pressing challenge and one that poses many safety concerns. A previous project (ConceptNet) executes multi-agent interaction-aware trajectory prediction using a graph neural network. This project aims to use the predicted trajectories to create scenario-specific emissions that form the cost functions of a Linear Quadratic Regulator (LQR) to be used as the planner. The cost function of the LQR is set up to maximize the distance from (predicted trajectories of) neighboring cars while minimizing the distance from a reference trajectory. Results show that different scenarios benefit from varying parameters of the LQR cost functions. Further work can be done in training a neural network to emit these parameters given an input scenario.

Effect Of Porosity in Vortex Ring Formation Time Scales
Sebastian Banuelos
Mentors: Mory Gharib and Scott Bollt

Vortex rings are a commonly studied phenomenon in fluid mechanics due to their large presence in turbulent flow. They are flow structures generated when a body of water is forced through an outlet, causing a separation in the boundary layer at the opening, resulting in a rotating column of air. Gharib et al. proposed that vortex rings achieve a maximum circulation at a universal formation number. Using a piston-cylinder experimental setup, he described this characteristic number to be a stroke-to-diameter ratio of approximately 4.

In this project, the effect of porosity in formation time scales of vortex rings is studied experimentally. By allowing smaller streams to flow across its surface, porous bodies display different aerodynamic properties than a conventional solid plate. These jets interact with wake flow affecting the formation of vortex structures.

Thus, we will utilize perforated plates with industry-standard porosity ratios. By accelerating these plates through a water tank, we obtain velocity and vortex flow fields using Particle Image Velocimetry. By varying the porosity of such plate, we seek to identify the critical ratio at which flow transitions from wake to trailing jet behavior. Ultimately, porosity could serve as a potential parameter space to model the formation time scale of vortex rings.

Using Variability of Emission to Determine Presence of Black Holes in Galaxies
Diego F. Barcenas
Mentors: George Helou and Frank John Masci

The AGN (Active Galactic Nuclei) refers to the torus shaped region at the center of a galaxy. Observing instruments of AGNs such as telescopes NEOWISE/WISE (NASA's Near-Earth Object Wide-field Infrared Survey Explorer) and ZTF (Zwicky Transient Facility) perform a survey of the night sky, crossing the ecliptic poles. We categorize the information from a given galaxy collected by ZTF and WISE/NEOWISE, to determine the probability of a black hole being present in the galaxy's center. The measurements of luminosity were studied to estimate the variation, or fluctuation of the significant source of light. Fluctuations strongly correlate with the pretense of an accreting black hole in the center of a galaxy, being the source of energy or radiation from the galaxy. From there, given data from an arbitrary galaxy, a categorization can be made if a black hole is present or not.
Robotic Optical Ammonia Detection—Materials Acceleration Platform (ROAD-MAP)
Bryan Burnell
Mentors: John Gregoire and Ryan Jones

Automating the characterization of possible ammonia-generating electrochemical processes will greatly accelerate the search for a renewable method of ammonia production. The High Throughput Experimentation Group is currently working with several other labs to develop electrochemical reactors that will autonomously facilitate electrochemical processes to potentially produce ammonia from N2. Designing a Robot Solution Handling System to automatically prepare and and spectrometrically analyze the samples produced by such a reactor will allow the rapid characterization of electrochemical processes’ ability to produce ammonia. A flow cell was designed to have samples injected into a 0.04” ID electrolyte flow path, with a broad-band LED shining through a 3” long optical absorption path to be measured by a spectrometer on the other end. A Python program will then automatically analyze the collected spectra to determine the ammonia content of each sample.

Transforming Metal-Organic Materials Into Wide Band Gap Semiconductors and Metals by Using Direct Write Electron Beam Lithography
David. A. Castillo Lozada
Mentors: Axel Scherer and Scott Lewis

The ability to write structures at the nanoscale using lithography underpins all modern society. The electronic devices we take for granted contain integrated circuits, and the key component of those circuits are field-effect transistors (FETs). They have reduced in size by a factor of two every two years for over fifty years, following “Moore’s Law”. The roadmap for the electronics industry now assumes that this constant reduction of size will continue – at least until the mid-2020s. However, there is a significant challenge immediately ahead because to produce the latest microprocessor requires approximately 60 photomasks to fabricate each layer in the device. Unfortunately, to produce this, multiple materials and multiple processing steps are required and these are subject to failure. To alleviate this issue, we describe how metal-organic materials can be transformed from a highly insulating materials to produce a semiconductors and metals using an electron beam. This is of particular interest because it demonstrates that active semiconductor devices such as field effect transistors can be simple to produce with no photomasks or etching steps or impurity doping being required, which inherently drives the manufacturing cost's down while increasing the throughput.

Stability of Shock-Induced Separated Flow (SWBLI)
Kyla Cook
Mentors: Chih-Yung Wen, Jiaao Hao, and Tim Colonius

To optimize aeronautical performance, we must investigate the effects of shock wave and boundary layer interactions, which are observed frequently in practical situations and often become a limiting factor of aeronautical design. Obtaining a base flow allows for us to perform a stability analysis on the flow profile and helps us understand the transition between laminar and turbulent flow in shock induced separated flow. We first performed flow simulations using ANSYS Fluent and extracted a base flow at predetermined flow conditions. Then, we performed a stability analysis of the flow profiles to understand how the stability properties were altered by flow separation. The Navier-Stokes equations were linearized around the obtained base flow, which could then be reduced to an eigenvalue problem by substituting periodic perturbations in the streamwise and spanwise directions, thus creating a problem that could be solved using linear algebra tools.

mRNA Targets of miRNA-190b in Ovarian Cancer
Sophie Dalfonzo
Mentors: Stefán Sigurðsson and Karen Kristjánsdóttir

MicroRNAs (miRNAs) are short RNA sequences which downregulate or silence genes whose mRNA transcripts are partially complementary to the miRNA. MiRNAs bind to the RNA-induced silencing complex (RISC) and guide it to the target mRNA, where RISC blocks the translation of the mRNA into protein. The Sigurðsson lab previously found that expression of microRNA-190b (miR-190b) correlates to a higher survival rate in Luminal A estrogen receptor-positive breast cancer patients. Through immunoprecipitation experiments, they have shown that miR-190b interacts with, among others, the mRNA for the RFWD3 protein; lower levels of RFWD3 also correlated to a higher survival rate in patients. Interestingly, the group found that higher levels of miR-190b correlate to lower survival in ovarian cancer patients. This suggests that miR-190b may function differently in ovarian cancer cells than in breast cancer cells. To investigate this, we transfected two ovarian cancer cell lines with a biotin-labeled oligonucleotide mimicking miR-190b and performed immunoprecipitation to extract the mRNA associated with the miR-190b mimic. In the future, this miRNA can be aligned to the human transcriptome, and targets found through this method can be confirmed with Western blot analysis and luciferase assays.
Score-Based Diffusion Models for Photoacoustic Tomography Image Reconstruction
Sreemanti Dey
Mentors: Katherine Bouman and Berthy Feng

Photoacoustic Tomography (PAT) is a low-cost, diversely applicable and relatively radiation free medical imaging technique [6]. One part of the PAT process is the reconstruction of the image itself from the signals that the process acquires, and there are three major ways to do the reconstruction. The most feasible method is model-based, which uses a model matrix to invert the measurements into the image [3]. In this work, we will use score-based diffusion models to solve the inverse problem of reconstructing the image from PAT measurements, creating a comprehensive and fast end-to-end pipeline for the process that is robust under varying conditions.

Modeling the Aging Eye: A Matlab Based Analysis of the Geometric Properties of the Zebrafish Eye
Marama Diaz-Asper
Mentors: Paul Donaldson and Justin Bois

As the aging population grows across the world, so do optic-based issues such as Presbyopia. In an effort to slow and treat the effects of optical ailments, research into how the geometry of various components of the eye, with the species zebrafish as a model, has been conducted. This project presents a matlab software which cleans, corrects, and analyzes components of the eye from an optical coherence tomography imaged zebrafish. This includes lens curvature, retinal thickness, and more, all as influenced by different refractive indices per component of the eye. From this, research can be conducted into the movement of the lens nucleus over time, as well as geometric changes in the eye as one ages. This will provide a necessary basis and tool for further research into the mechanisms of the aging eye.

Analysis of the Higgs Boson Pair Decay Channel in Final States With Two Bottom Quarks and Two Photons in Proton-Proton Collisions in CMS at the Large Hadron Collider
Elizabeth Field
Mentors: Harvey Newman and Irene Dutta

The Higgs Boson is a major element of the Standard Model Theory of particle physics, as it is responsible for the mass of every fundamental particle and explains the breaking of electroweak gauge symmetry. In order to understand it, we must study its production mechanisms and decay modes. In particular, we aim to do this through constraining the trilinear self-coupling constant, as the potential of the Higgs Field is theorized to be dependent on only that and the mass of the Higgs Boson itself. In order to do this, we perform $\gamma$ reconstruction through a combination of machine learning techniques trained on simulated proton-proton collision events that include two Higgs Bosons decaying to two bottom quarks and two photons ($HH \rightarrow b\bar{b}\gamma\gamma$), under the CMS detector and LHC conditions experienced by the experiment in 2017. We then use this data, in combination with data from the quantum chromodynamics (QCD) background, to identify and reconstruct these di-Higgs to $bb$-bar gamma gamma events, improve current methods of reconstruction, selection, and background suppression, and improve upon and determine final efficiencies for signal and background through machine learning based classifiers using different weightings and combinations of the kinematic variables describing these particle collisions.

Characterizing the Influence of Ascarosides on Ins-6 Expression in ASJ
Nerissa Finnen
Mentors: Paul Sternberg and Mark Zhang

Understanding how organisms make decisions in response to multitudes of sensory cues is fundamental for expanding the knowledge of organism behavior. In Caenorhabditis elegans interest for uncovering the mystery behind the behavioral stress induced alternative developmental stage (dauer) is abundant. Recent findings show that the ins-6 gene is essential in exiting dauer. However, the process can be impeded by stress; the principal factor being pheromone and its chemical molecules (ascarosides). The aim of the project is to illuminate the effect of individual ascarosides on dauer exit. To do so, C. elegans are exposed to the individual ascarosides upon exit. Through fluorescence tagging of the ins-6 genes in the ASJ neuron it is then possible to quantitatively measure gene expression to determine exit efficiency. At increased concentration of ascarosides, the ins-6 expression after exit was greatly diminished compared to unexposed nematodes. This followed behaviorally, as exposed C. elegans exhibited typical dauer traits, like reduced movement and coiled resting positions. The results characterize the effect of the ascarosides on the ins-6 gene and the behavior of the nematodes that fall in line with existing knowledge. A possible next step would be to ablate genes in C. elegans to verify what was observed.

Mousify: Fast Structure Calculation for Thermostability Validation
Jessie Gan
Mentors: Steven Mayo and Lucas Schaus

Antibodies are valuable therapeutics that require humanization for drug viability. Computational humanization models often generate large libraries of antibody sequences, which can be further improved with thermostability validation. To obtain more accurate thermostability calculations, researchers often make use of the protein...
structure as an input to their scoring functions. While recent advances in \textit{in silico} methods of structure prediction have increased accuracy to investigate protein properties, the most accurate structure prediction model, AlphaFold2, is not computationally viable to structurally validate protein sequence libraries on the order of millions. To accelerate the calculation of reliable antibody structures for these libraries, we combine Alphafold2 with homology modeling software, Promod3, for unknown, but closely related, structures. Our hypothesis is that homology modeling based on an AlphaFold2 template of a highly related structure is reasonably similar to an AlphaFold2 structure of the query sequence, orders of magnitudes faster, and near-indiscernible in thermostability calculations. Currently, the AlphaFold2 generated cluster representatives have been successfully calculated, and we find generally well modeled domains and distinct structural differences. We continue to train a classifier for identifying query sequence cluster membership, and are currently experimenting with various embeddings and models to improve performance.

\textbf{Latent Diffusion Models for Controllable Generation of Piano Music}

Adishree Ghatare  
\textit{Mentors: Yisong Yue and Yujia Huang}

While existing machine learning models can generate convincing music, these models do not allow fine-grained artist control on generation, limiting their utility in helping artists iterate quickly on their ideas. This work introduces an interpretable controllable piano music generation model using latent diffusion models, which have proved successful at generation in the image domain are extended here into symbolic music domain. Particularly, this work examines how several domain-specific tricks such as denoising objectives can improve performance, robustness, and expressiveness of a musical latent space for MIDI files. Ongoing efforts focus on using domain-specific rule-based guidance in diffusion and manipulating factor graph representations to enable long-range coherent generation, a problem still unsolved across domains.

\textbf{A Photosensor for the Fast Component of Barium Fluoride Scintillation Light}

Victor Gomez  
\textit{Mentors: David Hitlin, James Oyang, and Jason Trevor}

Through collaboration with the Bruno Kessler Foundation (FBK) and the Jet Propulsion Laboratory (JPL), a new generation of Silicon Photomultipliers is being developed with the ability to filter out light above 240nm. BaF2 has two emission bands, a fast and a slow component. The slow component has a decay time of 650ns and emits light with wavelengths above 240nm. The fast component has a decay time of 600-800 ps and emits light with wavelengths below 240nm. Such photosensors will be capable of detecting only the fast component of BaF2 scintillation light, improving the time resolution at which data can be captured. Properties of these new devices, such as gain, noise, and photon detection efficiency (PDE), were characterized in the lab in order to see them immediately applied in the Mu2e experiment. Monte Carlo computer simulations were also performed to test the properties of the scintillation crystal–photosensor system.

\textbf{Treatment of Bladder Cancer With Bubble-Powered Microrobots}

Claire Hays  
\textit{Mentors: Wei Gao and Hong Han}

Microrobots have the potential to greatly improve cancer treatment methodologies by allowing anticancer drugs to be targeted directly to tumor sites, allowing for higher efficacy treatment with fewer side effects. But, designing a microrobot for this purpose requires it to be able to travel rapidly, be easily directable, have a sufficiently long lifetime to allow it to reach its destination, and degrade naturally after attaching to the tumor. By designing a bubble-based microrobot, the microstreaming effects resulting from application of ultrasound waves can be optimized for high-speed motion. By incorporating iron oxide nanoparticles into the microrobot, the direction of its motion can be directed by magnetic fields. These crucial aspects of the microrobots’ function are tested in vitro and in vivo using mouse subjects, showing them to be effective in treating bladder cancer tumors, but continued work will need to be done improving and testing their function before use in treating cancer patients.

\textbf{Electrolessly Plated and Low-Temperature Annealed Ohmic Contacts to n-type GaAs for Low-Cost GaAs Solar Cells}

Hana Hisamune  
\textit{Mentors: Harry Atwater and Phillip Jahelka}

The Space Solar Power Project (SSPP) seeks to deploy large arrays of low-cost solar cells in space and wireless transmit usable energy back to Earth. III-V materials such as GaAs and InP are promising solar cell materials for SSPP, but they are hindered by requiring expensive metallization processes. Because ohmic contacts to III-V compounds are traditionally fabricated using vacuum evaporation and precious metals such as gold, an alternative cheaper, low-temperature method must be pursued in order to meet the cost and thermal-budget requirements of SSPP. In this project, we present an electrolessly plated Pd/Sn-based contact structure that becomes ohmic when annealed at temperatures less than 200ºC. The contact is fabricated using simple chemical baths to deposit Pd and Sn onto n-GaAs and relies on the solid phase regrowth of a Sn-doped GaAs lattice for the actual contact
formation—replicating the low contact resistivities obtained in Pd/Ge/Au-based systems at ~180ºC but using much lower cost processing. Through phase identification using x-ray diffraction, we demonstrate the rapid formation of a PdSn₄ intermetallic and the onset of ohmic behavior with contact resistivity of approximately 1Ωcm² at low temperatures. We investigate the phase formation and performance of the Pd/Sn n-GaAs contact at various annealing temperatures less than 200ºC and explore the feasibility of low-cost scalable ohmic contacts for SSPP applications.

**Utilizing Plasmid Machinery to Improve Syn61**
Ella Holland  
Mentors: Kaihang Wang, Jianyi Huang, and Jolena Zhou

Syn61 is a synthetic E. coli, created in Dr. Wang's previous research, which has a recoded genome with only 61 codons. This organism presents exciting potential for creativity in biological designs that take advantage of such a reprogramming. A current challenge of working with Syn61 in this manner is its relatively slow growth rate in comparison to its wild-type counterpart, MDS42. In order to create a variant with an improved growth rate, a conjugation plasmid is utilized to systematically replace segments of the Syn61 genome with MDS42 DNA from a donor library over multiple rounds of conjugation. This DNA is then integrated into Syn61 by recombineering, and the growth over time of the resulting clones is analyzed. Clones thus far have demonstrated potentially improved growth rate, and the project is moving forward with the goal of conjugating over shorter fragments of MDS42 DNA across multiple rounds to pinpoint a few recoded codons that could have caused the growth defect in Syn61. Additionally, to improve conjugation efficiency, the conjugation plasmid has been sequence optimized and cloned, and tested for conjugation efficiency.

**Mice in Manhattan: Navigation, Rapid Learning, and Memory in a Reconfigurable Maze**
Jennifer Hu  
Mentors: Markus Meister and Jieyu Zheng

Cognitive flexibility allows mice to quickly adapt to and memorize new paths through mazes. To observe this flexibility, we used the Manhattan maze, a novel 3D maze structure that can be easily modified using masks which selectively limit the traversability of the maze. Masks tested include O, a one-decision training mask to acclimatize the mouse to the maze; and A, B, and C, distinct mostly-linear 9-decision masks with similar local turn patterns and distances. Mice were either given a 1 day control test wherein scent tracks in the maze were shuffled halfway through the day; or a 2 day memory and learning test consisting of one training day with masks O and A, and one testing day with masks A, B, and C. A total of 20 mice were tested: 5 were given the control, and 15 began the 2 day test. Of 11 mice that successfully completed at least 10 round trips through mask A on day 1, all showed similar improvement in performance over time, and demonstrated quick mastery over all 9-decision masks in just a few hours.

**Facial Expressions in Mice**
Joseph H Kim  
Mentors: David J. Anderson and Amit Vinograd

Investigation of emotional states in mice have been hindered by the inaccessibility of their internal states. We demonstrate a novel method of extracting facial expressions from head-fixed mice, interpreting them, and comparing them across trials, mice, and setups. Facial expression analysis on optogenetically stimulated mice identifies unique, scalable, and persistent facial expressions associated with aggression and mating behaviors. Mouse facial expressions induced by different stimuli—physical and optogenetic—are unique and distinguishable at millisecond time scales. The scalability, generalizability, and persistence of emotion states are reflected in their respective facial expressions, suggesting that the facial expressions can be used as an objective readout of emotional states in mice. Furthermore, the direction of certain features correlates with and may encode the valence of the emotional state. Our method, hence, provides an objective tool for measuring and comparing emotional states in mice.

**Observational Signature of a Massive Neutral Gas Reservoir in the Intracluster Medium of a Galaxy Cluster at z=5.4**
Umran S. Koca  
Mentors: Kasper Elm Heintz and Melany Hunt

In the current concordance cosmological model, galaxies and clusters are thought to be formed through hierarchical structure formation in matter overdensities. The formation and evolution of galaxies and in particular their efficiency at producing stars and initiating the large-scale reionization of the universe is expected to predominantly occur in these regions. Identifying these overdensities of cold, neutral gas needed to fuel this process, is significantly limited due to the inaccessibility of the hyperfine 21-cm transition from neutral atomic hydrogen (HI) at these redshifts. However, HI can be probed in an alternative way through the Lyman-alpha features, imposed in absorption on bright background sources such as quasars or gamma-ray bursts, or in rare cases on galaxy spectra as well. With the James Webb Space Telescope (JWST), we have identified several galaxies
in close projected distance but in the background of a proto-cluster at z=5.4 showing prominent Lyman-alpha absorption features. There is preliminary evidence that the strong Lyman-alpha damping feature observed in these galaxies are evidence of HI in the foreground cluster opposed to gas in the galaxies themselves. To solve this, I use Bayesian inference in conjunction with least squares and Nelder Mead fitting methods to constrain the redshift of the absorption feature, modeling it as a Voigt profile. Further, using the photometric template fitting code, EAZY, I extend these models to include reconstructed spectra with an added Lyman-alpha damping wing. Based on these results I identify 3 galaxies that show damped Lyman-alpha absorption features (N_HI > 10^{20} cm^{-2}) consistent with the proto-cluster redshift, excluding a local origin at > 3 sigma. From this, I estimate the size and mass of the HI in this cluster overdensity. This is the first such detection, and provides valuable insight into the early processes of galaxy and structure formation when the universe was less than 1 Gyr old.

**Early Detection of Alzheimer’s Disease in Non-Symptomatic Older Adults: Identifying Potential Biomarkers Using Subliminal Processing Paradigms**
Shrujana Kunnam  
**Mentors: Shinsuke Shimojo and Lara Krisst**

Alzheimer’s disease (AD) is an irreversible neurodegenerative disease characterized by the progressive loss of memory, cognitive ability, and executive function. Although there is no existing treatment, early intervention can delay disease progression. The most frequently used diagnostic biomarker for AD involves measuring Aβ and tau protein levels in an individual’s cerebrospinal fluid. However, this technique is expensive and invasive. The current project aimed to identify a robust, non-invasive diagnostic for preclinical AD to enable early detection and response. We examined participants’ performance during subliminal processing tasks rather than more explicit working memory or executive function tasks which typically only capture abnormalities during later stage AD. In one study, we recorded EEG data during a subliminal saccade/antisaccade task from cognitively healthy older adults with differing levels of amyloid/tau pathology at the Huntington Medical Research Institutes. Previous research has shown that eye movements are preceded by a shift in covert attention, as indexed by the N2pc ERP component, particularly under conditions which require increased attentional filtering. Therefore, we compared the N2pc component in participants with differing risk for AD during congruent/incongruent subliminal priming conditions to examine the hypothesis that high-risk participants have decreased attentional resources compared to low-risk participants.

**Appearance of Entropy in the Growth of Cardinalities of Orbits of Flags**  
Ryan Leal  
**Mentor: Juan Pablo Vigneaux Ariztia**

For certain groups, parabolic subgroups appear as the stabilizer of flags under some action that the group takes on a vector space. The cardinalities of these orbits asymptotically reveal entropies of certain systems. Interpreting their quotients as multinomial coefficients, the multiplicative chain rules that occur in these cardinalities appear as additivity of entropies asymptotically. Symmetric groups are particular instances of finite reflection groups; we study the aforementioned quotients for such groups and their asymptotic behavior in connection with entropic functionals. Their Dynkin diagrams provide a more unified description of the multiplicative chain rules that appear. We also introduce flags of vector spaces as natural objects on which the groups act on and that are stabilized by the parabolic subgroups. We also investigate the asymptotics for the Symplectic and Orthogonal groups. For these finite Chevalley groups we investigate the chain rules that appear from interpreting their quotients as multinomial coefficients. Further research could include a general construction of the asymptotics for quotients of arbitrary finite Chevalley groups.

**Scalable Learning of Non-Gaussian Graphical Models**  
Sarah Liaw  
**Mentor: Ricardo Baptista**

In recent literature, the Sparsity Identification in Non-Gaussian Distributions (SING) algorithm has been used to identify conditional independencies of a collection of non-Gaussian random variables. The SING algorithm utilizes the relationship between the sparsity of a probabilistic graphical model and the sparsity of a transport map representing the distribution of the random variables to achieve this task effectively. When dealing with high-dimensional distributions, however, the computational cost of the SING algorithm becomes intractably high. In our study, we propose a localized SING algorithm, which aims to learn the conditional independencies of a large number of random variables using neighborhood selection methods. For Gaussian distributions, we demonstrate the relationship between neighborhood selection with the Lasso and linear transport maps. For non-Gaussian distributions, we extend the neighborhood selection method to develop the localized SING algorithm. We will compare the computational runtime and performance of the localized SING algorithm with the original SING algorithm. Finally, we will assess the algorithm’s theoretical and experimental consistency in recovering the true graph with high probability as the sample size of the underlying distribution increases. The evaluation includes non-Gaussian datasets like the butterfly distribution and Lorenz-96 dynamical system.
Assessing Cell Motility of *Escherichia coli* Using the Subtractive Photonics Process in 180 nm CMOS
Antônio Victor Machado de Oliveira
Mentor: Ali Hajimiri

This study explores the optogenetic manipulation of bacterial motility using an integrated circuit for targeted applications such as pathogen elimination and drug delivery. The research relies on the controllable movement of *E. coli*, a widely studied model organism, which exhibits distinctive run and tumble states. Prior efforts using chemotaxis for motion control have highlighted limitations in spatial precision. To overcome this, optically regulated genetic circuits have been introduced, employing a phosphoprotein phosphatase to govern flagella rotation. With previous studies demonstrating complex pattern formation on a petri dish, bacterial motility is shown to be controlled in microchip environments using integration of photonics and fluidics in a CMOS chip. The chip’s design, employing subtractive photonics, facilitates optical illumination control in specific zones. A bifurcated fluidic path, when illuminated, induces swimming or tumbling bacterial behavior, enabling differential measurement of concentration through biofluorescence encoded in genetically engineered *E. coli*. Successful outcomes hold potential for broader optogenetic applications, including in vivo bacterial manipulation for therapeutic purposes.

Designing an Optimized Robotic Ankle for a Bipedal Robot
Julian Millan
Mentors: Aaron Ames and Adrian Ghansah

This project aims to redesign a proper ankle for a bipedal robot built by Caltech’s AMBER Lab. Moving on from stick feet, this new design will have a motorized ankle allowing for rolling and pitching motion. The design will also include a passive toe joint that would allow the robot to have a more efficient walking gait. This form of ankle design will allow for greater balance and efficiency and will also allow the robot to travel rougher terrain than the smooth and soft lab floor. The primary goal of our work this summer is to create a fully fleshed out 3D model in an application such as SOLIDWORKS that includes all of our motorization, attachments, and main body of the ankle. At the end of the summer, a 3D printed model will be created to better demonstrate the mechanism of the ankle. The proper creation of this design will allow further progress to be made on the robot and further ankle design iterations to be made.

Physically Informed Machine Learning Emulators of Aerosol Activation Trained on a Lagrangian Particle-Based Model
Mikhail Mints
Mentors: Tapio Schneider and Anna Jaruga

A significant part of the uncertainty in climate change forecasts arises from microscopic interactions within clouds, which occur on a scale that is much smaller than the resolution of current climate models. Since it is too computationally expensive to directly simulate these processes, climate models must rely on microphysical parameterizations. This project focuses on modeling aerosol activation – the process by which water vapor condenses onto aerosol particles to form cloud droplets. Climate models approximate aerosol populations as a set of lognormal modes, and thus the competition between aerosol particles for the available water vapor needs to be parameterized. The Abdul-Razzak and Ghan (ARG) parameterization, currently used in many climate models, makes approximations that cause it to produce inaccurate results in certain conditions. The goal of this project is to construct a data-driven aerosol activation emulator trained on PySDM – a detailed Lagrangian model that represents the interactions within a population of particles from first principles using the Super-Droplet Method. Existing physical approximations based on ARG are added to the training data, and the performance of several machine learning techniques is evaluated against PySDM. Previous work is extended by constructing emulators for more generalized, multimodal aerosol distributions.

Measuring Ice Grain Growth Rate in the Caltech Dusty Plasma Experiment From Size and Wavelength Dependent Laser Extinction
Robert Morgan III
Mentors: Paul Bellan and Andre Nicolov

The Caltech Ice Dusty Plasma Experiment studies the dynamics of ice grains suspended in a weakly ionized plasma at T=80-150 K. In one to two minutes, water vapor forms elongated fractal-like ice grains that can grow up to 750 microns. While there is substantial research on the ice grains once they stabilize in size, the growth rate is unexplored. One possibility for tracking growth rate is by measuring the attenuation of light passing through the dusty plasma. A laser beam emitting two wavelengths at 532 nm and 1064 nm passes through the plasma, and the exiting beam is split by a wavelength-dependent beamsplitter and measured using two photodiode detectors. When the grain sizes are comparable to the wavelength, Mie scattering occurs. The degree and direction of scattering depend on the incident angle, particle size, grain number density, and wavelength. As the grains grow, scattering from 532 nm will differ from the 1064 nm. This difference will indicate the growth rate and changes in other parameters such as number density.
Nitrogen Fixation via Proton-Coupled Electron Transfer Using a Pyrene-Based Mediator
Ramona Wanjiru Murugu
Mentors: Jonas C. Peters and Catherine G. Romero

In the quest for efficient electrochemical ammonia synthesis, the hydrogen evolution reaction (HER) often outcompetes the nitrogen reduction reaction (N2RR) due to the limited stability and selectivity of current catalysts. To address the HER dominance, recent efforts have focused on tandem catalysis, which involves a molecular complex for reduction combined with a co-catalyst for photocatalytic proton-coupled electron transfer (pePCET), which can be electrochemically recycled at comparatively mild potentials. This innovative approach harnesses light to provide additional driving force without resorting to harsh potentials. By utilizing a modified ferrocene complex with an amine base and an anthracene photosensitizer, irradiation induces intramolecular electron transfer, yielding a high-energy anthracene radical anion colocalized with a proton on the amine base, able to deliver H-atom equivalents to N2RR intermediates. To further enhance the process, switching to a pyrene-based mediator with an extended excited state lifetime of 89.39 ns is proposed to improve stability and quenching yield of the charge separated state. We discuss the synthesis of this novel pyrene-based mediator, characterize the new compound, and compare its performance to previously studied cobaltocene and anthracene-based mediators.

A Joint-Sentiment Topic Modeling Approach to Examining the Effect of Social Media Discussions on Gaming Activity
Shreya Nag
Mentor: Michael Alvarez

This research project aims to investigate the relationship between discussion on social media and real-world events in the context of online gaming, with a specific focus on the game Call of Duty. The primary objective is to explore the connection between online sentiment and game updates. Leveraging Python, we will collect and preprocess data from Reddit and Activision's proprietary sources, enabling us to visualize posting patterns and keyword trends. We will utilize joint-sentiment topic modeling to estimate sentiment and topics in daily social media posts, revealing insights into player experiences, including issues such as abuse and harassment. Our work provides a systematic approach to uncovering the relationship between social media conversations and online gaming engagement. The project's conclusions offer valuable insights for game developers and researchers alike, shedding light on the dynamics between player sentiment and usage patterns. The research aims to contribute to understanding how online communities influence gaming behavior and to measure players' exposure to negative experiences.

Analysis of Higgs Boson Pair Production in the Bottom Quark-Antiquark Pair and Two Fully Hadronic Vector Bosons Final State Using Proton-Proton Collision Data in CMS at the Large Hadron Collider
Andres Nava
Mentors: Harvey Newman and Nan Lu

The Higgs boson, postulated in 1964 and discovered in 2012 at CERN's Large Hadron Collider, is fundamental to understanding how elementary particles acquire mass. Since its discovery, significant attention has been directed towards the study of Higgs boson pair production, providing insights into vital parameters of the Higgs field. Our research builds on a current analysis searching for standard model nonresonant double Higgs production, targeting the bottom quark-antiquark pair and all-hadronic final vector boson pair states in the scenario where both Higgs bosons are highly Lorentz-boosted by investigating the vector boson fusion production channel. By employing the latest machine learning techniques, including ParticleNet and Particle Transformer, we achieve a heightened accuracy in identifying jets indicative of Higgs decays, crucial for enhancing signal sensitivity and suppressing potential backgrounds. Initial investigations have been conducted on simulated data, with plans to extend our research to real datasets.

Impact of Pancreatic Adenocarcinoma on the Duodenum Microbiome in Mouse Models
Paulina Naydenkov
Mentor: Rustem F. Ismagilov

Abstract withheld from publications at mentor's request.

Developing Custom Software for a Miniature Potentiostat With Functionalized Aptamer Based Sensors
George Ore
Mentors: Ellis Meng, James Yoo, Emmanuel Ramirez, Christopher Larson, and Alireza Marandi

In the realm of biomedical MEMS technology, the demand for compact, adaptable instrumentation has surged, particularly for wearable applications necessitating real-time electrochemical analysis. This abstract underscores the imperative to develop software tailored for a miniaturized potentiostat, primed for wearable deployment, and specifically geared for continuous square wave voltammetry (SWV) measurements. The development of the software involves several key stages. Initially, comes the planning phase. First, a comprehensive analysis of the potentiostat's hardware specifications and capabilities is conducted to determine the required software features.
Next, the graphical user interface (GUI) is designed to provide an intuitive platform for researchers to define experimental parameters, such as applied potentials, scan rates, and data acquisition intervals.

During the proceeding implementation phase, programming languages such as Python are employed due to their versatility and extensive libraries for scientific computing and graphical representation. Low-level communication protocols are established between the software that users access and the code on the potentiostat's hardware components to enable real-time parameter adjustments and data retrieval.

The customizability of the software is imperative as the requirements of the lab evolve through successive iterations, the software is continuously refined and expanded. The resulting software serves as a vital tool for researchers to conduct their work and the ever-fluctuating demands of the electrochemical research community.

**Electron-Phonon Interactions in the Density Matrix Formalism**

Vibha Padmanabhan

*Mentors: Marco Bernardi and Ivan Maliyov*

Understanding transport in semiconductors is important to improve the working and efficiency of devices like LEDs, transistors, and solar cells. A particularly important transport phenomenon is scattering: the deflection of electrons and holes from their original paths due to interactions with other particles, such as phonons, in the system. The Bernardi group at Caltech has developed PERTURBO, an open-source software which computes from first principles the scattering processes between charge carriers, defects and phonons in solid state materials using the Boltzmann equation. The Boltzmann equation is the semi-classical limit to the equation of motion for the density matrix of the system. In this project we derive the complete dynamics of the density matrix of an electron-phonon system. This will give us new information about coherences between states and the effects of optical pulses, which is important to better understand the optical and electronic properties of semiconductors. We also begin to develop a prototype implementation of the dynamics with the goal of extending the capabilities of PERTURBO.

**Improving Repeatability in Minimum Autoignition Temperature Testing in Aviation Fuels**

Isabella Pagano

*Mentors: Joseph E. Shepherd and Charline Fouchier*

The thermal autoignition of jet fuel poses substantial challenges to maintaining safety in the aviation industry. Currently, the ASTM-E659 test is the industry standard for determining the minimum autoignition temperature (AIT) of aviation fuels. This test consists of the injection of a small volume of fuel into a furnace heated to a controlled temperature; ignition is determined from visual observations and thermocouple data. We seek to improve the repeatability of the results from the ASTM-E659 test by automating the fuel injection into the ASTM furnace. We designed a machine which allows for the complete automation of the ASTM-E659 test by lowering a syringe into the testing furnace and injecting a set volume of fuel via a motorize slide, then raising this syringe component and rotating the assembly via a turntable connected to pneumatics. This mechanism allows for the control of the fuel volume injected and the rate of injection. It also minimizes the incidental heating of the syringe and fuel due to proximity to the furnace, providing more consistent results. The success of the machine was then determined by testing the ignition of hexane against existing test data.

**Investigating the Impact of Fluid Accumulation on the Mechanical Properties of 3D Printed Alveoli Models Mimicking Lung Tissue**

Sophie Polidoro

*Mentors: Kaushik Bhattacharya and Jin Yang*

Respiratory gas exchange hinges upon dynamics of alveoli, minute and elastic air sacs within the pulmonary system. With each breath, these microstructures undergo cyclic expansion and compression, facilitating gas exchange. However, diverse pathological conditions disrupt this process causing mucus and anomalous fluids to accumulate, leading to pulmonary edema. This study aims to understand the interplay between fluid accumulation and alveolar mechanical characteristics, to elucidate underlying mechanisms for prompt diagnosis and intervention. To identify how periodicities and geometries affect mechanical attributes of lung tissue, we 3D-printed soft elastic resin models based on this architecture in various sizes. The samples are characterized using uniaxial tension and compression experiments at different loading rates to compare their material mechanical behavior. Next, we explore effects of fluid accumulation on alveolar behaviors by filling 3D-printed alveoli samples with different liquids and hydrogels in different viscosities and conducting needle-induced cavitation experiments to investigate how mucus impacts alveolar responses. Additionally, we plan to integrate Digital Image Correlation to enable full-field spatiotemporal measurement of dynamic deformations during the expansion-compression cycles. By converging these avenues of inquiry, this research endeavors to enhance the scientific community's comprehension of pulmonary edema etiology and progression, ultimately advancing expedited diagnosis and targeted therapeutic interventions.
**Actuator Communication Attempts for AMBER Lab’s Bipedal Robot ADAM**

Juan Renteria  
*Mentors: Aaron Ames and Adrian Boedtker Ghansah*

From helping in labor intensive jobs to helping individuals with mobile disabilities, humanoid robots have the tremendous potential for supporting humans in a vast number of ways. The AMBER Lab at Caltech is working on developing ADAM, a humanoid robot, where the goal is to create generalized dynamic 3D walking algorithms that can be transferred to other humanoid systems. The first step in creating the electrical system that will lie inside ADAM is to establish communication with the actuator that would be used. Communication with the actuator used for ADAM would occur through a communication line that includes a microcontroller and a transceiver embedded in the system. The primary actuator discussed is the A1 Unitree Actuator. After exhausting all the paths for communication with no success, and due to lack of information from the company, it was decided to halt more attempts at communication with the A1 Unitree Actuator. The next actuator chosen is the CubeMars T-Motor AK-Series, which is currently going through another testing stage.

**Physics-Informed Neural Operator for Learning Schrödinger Bridges**

Jeff Sun  
*Mentors: Anima Anandkumar and Julius Berner*

This study delves into the capabilities of physics-informed machine learning methodologies for tackling the Schrödinger Bridge (SB) Problem, a mathematical problem centered on the evolution between two probability distributions. Originating from Erwin Schrödinger's 1931 proposition, the SB problem has recently gathered attention due to its significance in contemporary machine learning as a generative model. Traditional methodologies often encounter difficulties in high-dimensional contexts, leading to the exploration of physics-informed neural networks (PINNs) and physics-informed neural operators (PINOs). These methods leverage physical knowledge embedded in partial differential equations (PDEs) to enhance modeling accuracy. Additionally, the study is investigating the use of Gaussian process representation to model PINOs, offering a computationally efficient solution for high-dimensional problems. This research extends its experimental scope to n-dimensional Gaussian Mixture Models and high-dimensional synthetic datasets, such as the Funnel problem and Double Well problem. Preliminary findings underscore the potential of PINNs in approximating solutions across varying complexities and dimensions. Though the findings are encouraging, they highlight areas needing refinement and the potential of PINOs in advanced modeling for high-dimensional datasets. This exploration lays the groundwork for future research in the domain of physics-informed learning and its implications for generative modeling.

**Testing the Capabilities of SAM**

Kieran Vlahakis  
*Mentors: Ashish Mahabal and Asitang Mishra*

In January 2019, the CDC reported that from 2015 to 2019 nearly half of all lung cancers were diagnosed at a distant stage when survival is lowest [1]. Early-stage cancer is often curable, but detecting it is challenging. Low-dose helical computed tomography (LDCT) has become a popular early detection strategy, however, with high false-positive rates it is not without limitations [2]. The purpose of this study is to see if we can alleviate some of these issues with the inclusion of artificial intelligence (AI) models in cancer diagnosis. This is hoped to be achieved through the use of computer vision tools that are capable of identifying and highlighting the features present in lung nodule scans. So far, we have been able to successfully use Meta’s recently released image segmentation tool, “Segment Anything Model” (SAM), to annotate singular slices of medical CT scans. This is done using the model’s automatic mask generation feature to overlay masks on top of each given slice. With a little finetuning, it is hoped that these annotations can be used at a later time to generate annotated 3D images of lung nodules.

References:  
**Contract-based Design of Autonomous Electric Automobiles Using Pacti**
Kenadi Waymire  
*Mentors: Richard Murray and Inigo Incer*

Issues arise within the design of specifications of complex engineering systems, largely due to human error. Utilizing contract-based design (namely assume-guarantee contracts) allows engineers to mitigate many of said issues. In this project, we use contract theory and a Python package Pacti to model an autonomous electric vehicle capable of being used to answer various questions that may emerge during such a design process. Examples of such questions include cost to efficiency comparisons, battery lifespan, and vehicle driving range.

**An Analysis of Hydrogen Dissociation and Ionization Rate Constants for Applications in Gas Giant Atmospheric Entry Probe Heating Simulations**
Jacob Wolmer  
*Mentors: Guillaume Blanquart and Alex Carroll*

The software used to calculate the heat flux experienced a probe entering an atmosphere at hypersonic velocities, velocities greater than five times the speed of sound in the gas, needs to accurately predict the rate of the reactions that will occur in the atmosphere directly in front of said probe. At these velocities, the gas can be heated to tens of thousands of degrees kelvin causing it to undergo thermochemical and ionization reactions, the rate of which affects the heating experienced by a probe. This study focused on the rate of Hydrogen dissociation and ionization rates as the atmospheres of the gas giants mostly consist of hydrogen. This analysis involved a review of the literature of both experimental and theoretical calculations as well as a recalculation of some of the rates. In this analysis, dissociation and recombination rates were considered as they allow for room temperature observations, while dissociation rates are measured between 2500K and 20,000K. A similar analysis was conducted for the ionization rate of dissociated hydrogen. However, this could only include high temperature rates as hydrogen ionization requires collisions of over 10.2 eV (11600K), which only occur at high temperatures. We have proposed fitted rates for each of these reactions.

**Role of Serotonin in Sleep Behaviors of Zebrafish and Generation of UAS/GAL4 Transgenic Zebrafish Lines**
Alanna Yelland  
*Mentors: David Prober and Grigorios Oikonomou*

Although sleep is a common phenomenon among animals, the genetic mechanisms of sleep are still relatively unknown. Serotonin (5-HT) has been shown to play a part in sleep, but its true role is a bit unclear. Thus, part of this project seeks to gain understanding of the role of 5-HT in sleep. tph2-incross zebrafish were video-tracked with programmed day and night conditions and analyzed for their sleep behaviors, then were genotyped using polymerase chain reaction and electrophoresis to understand the relationship between the tph2 gene, which codes for a protein that is responsible for catalyzing 5-HT synthesis, and sleep behaviors. Additionally, different combinations of tph2; nf1a; nf1b fish were crossed to test how the nf1 gene interacts with tph2. A secondary part of the project involves using the UAS/GAL4 system to generate transgenic lines that allow us to manipulate neuronal activity. To do this, transgenic fish with either the 5xUAS:rsChRmine; huc:gal4; casper+/- or 5xUAS:zfTRFV; huc:gal4+/-; casper+/- genotype were outcrossed with TLAB fish to produce progeny that were later screened for the desired UAS transgenes through fluorescent microscopy. By identifying founders with the UAS transgenes, these fish can later be studied and further understood.

**Behavior Flexibility and Neural Representations of Humans, Mice, and RL Models in Navigation**
Alina Zhang  
*Mentors: Pietro Perona and Rogério Guimarães*

In the realm of behavioral adaptations, understanding how different species exhibit behavior flexibility is a captivating avenue of exploration. Our research delves into this fascinating domain, focusing on humans, mice, and reinforcement learning (RL) models within navigation tasks. Behavior flexibility, defined as the capacity to adapt to varying circumstances, plays a pivotal role in survival and decision-making across species. Through a comparative approach, we analyze navigation behaviors of humans and mice using the versatile Manhattan Maze framework. By studying their strategies, we aim to uncover shared patterns and distinctive adaptations, potentially revealing conserved neural mechanisms underlying these behaviors. Moreover, we investigate whether RL models can replicate the observed behaviors in both humans and mice. Our exploration delves into different RL architectures, both model-based and model-free, aiming to discern the extent to which these computational models capture the intricate cognitive processes involved in navigation tasks. Furthermore, we delve into the neural basis of behavior flexibility, analyzing neuronal representations in both mice and RL agents navigating the Manhattan Maze. This analysis offers insights into the convergence between biological organisms and computational models. Overall, we aim to unravel fundamental principles governing adaptive behaviors, fostering broader implications for decision-making and survival strategies.
**Slow Intercellular Calcium Wave Dynamics in Shoot Apical Meristems**
Claire Zhang  
*Mentors: Elliot Meyerowitz and Ting Li*

Roughly 90% of the world’s plants are flowering plants, and moreover, at least 80% of human nutrition is derived from flowering plants—gaining a comprehensive understanding of the mechanisms behind plant development has paramount implications for climate change and human welfare. At the tip of each shoot in every flowering plant are shoot apical meristems (SAMs), a collection of self-maintaining stem cells for shoot, leaf, and flower development. This project observes and analyzes the different calcium dynamic responses induced in *Arabidopsis thaliana* SAMs by treating the dissected SAM with various neurotransmitters, particularly L-glutamate, glycine, and D-serine. Testing of these reagents on glutamate receptor-like (Glr) mutant lines is performed to determine channel specificity. Results show that both L-glutamate and glycine target Glr channels in the SAM. Characterization of the calcium dynamic responses are made visually with the use of a transgenic line with calcium ion fluor indicators (GCaMP3) and quantified using ImageJ, a post-processing image software, to produce fold-change plots. Additionally, the effect of lidocaine on these reagents will be tested to determine if lidocaine has any blocking effects on the neurotransmitters like it does in a normal neural environment. Synergistic effects between various combinations of neurotransmitter reagents will also be explored.

**Provide a GUI and Web Platform for Calculations of SNR and Exposure Time With PSIsim and Specsim for TMT-MODHIS and Keck-HISPEC**
Huihao Zhang  
*Mentors: Dimitri Mawet and Ashley Baker*

PSIsim and Specsim are two Python packages utilized for simulating the signal-to-noise ratio (SNR) for the spectroscopic characterization of exoplanets with TMT-MODHIS and Keck-HISPEC. PSIsim and Specsim employ Phoenix and Sonora models to simulate stars and planets and the Mauna Kea Sky Emission model to account for the noise from the sky background. Both simulators implement instrument throughput budgets and AO-driven coupling efficiencies, as well as thermal emission budgets from TMT-MODHIS and Keck-HISPEC. The simulators compute the total number of photons arriving at the detector per second and the associated noise level. We have refined and updated the functionalities of both PSIsim and Specsim. Based on these advancements, we are developing a comprehensive graphical user interface (GUI) that will serve the broader community, accompanied by a dedicated web portal. These platforms aim to calculate the SNR and determine exposure times specific to TMT-MODHIS and Keck-HISPEC across varied observing scenarios and science cases.