Caltech
Student-Faculty Programs

Session L Abstracts

Framing artificial intelligence in law through science fiction
Elizabeth J. Won
Mentor: Jennifer A. Jahner

Using science fiction narratives and current legal disputes and publications, this project analyzes how AI is alternately conceptualized as an autonomous agent or a mechanical tool, an extension of human intention. Each metaphor carries distinct implications for legal questions of liability and rights. Science fiction works like *Klara and the Sun* by Kazuo Ishiguro, *I, Robot* by Isaac Asimov, and stories by Philip K. Dick exemplify how metaphors can impact legal reasoning. *Klara and the Sun*, *Do Androids Dream of Electric Sheep?* and stories by Asimov foreground AI as a quasi-agent, highlighting issues of empathy and agency, while *Minority Report* and other Asimov works explore how dangers can arise from human misuse of AI tools. This tension becomes evident in *Mobley v. Workday*, a current employment discrimination case in which Workday defends its AI-driven hiring platform as a neutral tool, while plaintiffs argue that its design enables systemic bias. The case highlights the complicated assignment of responsibility. By situating these narratives alongside current legal controversies, the project shows how law's treatment of AI is bound by the language we use to describe it.

Neural mechanisms of context-guided goal pursuit in humans
Aleksandar Marinkovic
Mentors: John P. O'Doherty and Sneha Aenugu

Context guides our goals and sculpts the value representations for our actions in the world. In this study, we investigate the neural and computational mechanisms by which context modulates goal selection and subsequent value estimation of the state space. We designed a rich naturalistic navigation paradigm where the goals locations are explicitly modulated by the hidden context. Participants sample visual clues from the environment to accumulate evidence in favor of multiple contexts and selectively pursue goals based on their inference of the hidden context. We use Bayesian reinforcement learning to account for decision-making patterns pertaining to value estimation based on contextual ambiguity. We plan to investigate this computational hypothesis in conjunction with neuroimaging data acquired through fMRI to identify neural mechanisms of computations underlying contextual goal pursuit in humans.

Random utility with aggregated alternatives
Yuexin Liao
Mentor: Kota Saito

This paper studies when discrete choice data involving aggregated alternatives such as categorical data or an outside option can be rationalized by a random utility model (RUM). Aggregation introduces ambiguity in composition: the underlying alternatives may differ across individuals and remain unobserved by the analyst. We characterize the observable implications of RUMs under such ambiguity and show that they are surprisingly weak, implying only monotonicity with respect to adding aggregated alternatives and standard RUM consistency on unaggregated menus. These are insufficient to justify the use of an aggregated RUM. We identify two sufficient conditions that restore full rationalizability: non-overlapping preferences and menu-independent aggregation. Simulations show that violations of these conditions generate estimation bias, highlighting the practical importance of how aggregated alternatives are defined.

Data-driven prediction of land use change using multi-modal machine learning
Kiran K. Pabla
Mentor: Hannah Druckenmiller

Land-use change plays a central role in shaping both environmental conditions and economic outcomes. Over the past century, large-scale ecosystem conversion has enabled sustained economic growth and facilitated food production to be sufficient enough to support a growing global population. However, at the same time, human well-being depends critically on ecosystem services, such as air and water filtration and natural hazard mitigation, that are rarely priced into markets and therefore often undervalued in land-use decision-making. Determining where land-use change is most likely to occur is essential for guiding conservation strategies, particularly under the ongoing conditions of accelerating urbanization and mounting environmental stressors that we are facing in today's society. Thus, to address this need, we strived to develop a data-driven model to predict land-use transitions over a twenty-year time range. The model is trained on historical data collected from 1996 to 2016 and is designed to be applied toward forecasting future land-use changes. Existing models often struggle to capture the complexities of land conversion across different geographic and socio-economic conditions. Most rely primarily on structured tabular data, making it difficult to generalize across diverse regions. This project seeks to overcome these limitations by integrating high-resolution satellite imagery with datasets consisting of climate records and economic indicators such as property values and land prices through a multi-modal learning framework.

Genomic and morphological insights into novel spirochete morphotypes occurring with sulfur-cycling microbial sediment rafts
Anna I. Piland
Mentor: Jared R. Leadbetter

The phylum *Spirochaetota* contains some of the largest and most morphologically unique bacteria known to mankind. These spiral-shaped bacteria move through viscous environments using periplasmic flagella, with some species reaching lengths up to 500 µm. This project aims to uncover more details of spirochete classification and evolutionary relationships by focusing on both marine bacteria and novel freshwater forms. Planned comparative genomic sequencing of aquatic spirochetes will provide the opportunity to update phylogenetic placement and clarify relationships to other spirochetes. Upon the discovery of *Spirochaeta plicatilis*-like organisms, various small spirochetes, and two previously undescribed uniquely shaped spirochetes in sediment rafts from Caltech's Beckman Behavioral Biology pond, community samples enriched with these spirochetes were gathered for DNA extraction and planned metagenomic analysis. Through microscopic analysis, the latter two morphologically conspicuous spirochetes were determined to be of unprecedented dimensions, with wavelengths of around 1 to 1.2µm for one type and wavelengths as small as 0.4 to 1µm in the other, dependent on organism orientation, with both sharing a large amplitude of 0.5µm. Based on its morphology, spatial relationships, and behavior, the morphotype with the smaller "slinky"-like wavelength is potentially a novel species that remains undocumented in scientific literature.

Cultivation and analysis of aquatic anaerobic oxalotrophic methanogenic microbial communities
Wendy Wang
Mentors: Jared R. Leadbetter and Yuk L. Yung

Methanogens are obligate anaerobic archaea that produce methane from their metabolism, using various substrates such as H2 and formate to reduce CO2 into methane. Here, we investigate the possibility of a single oxalotrophic methanogenic organism, or the characteristics of a methanogenic oxalotrophic community of organisms. Using environmental samples (termite gut and BBB pond) put into defined media, we extracted an oxalate-dependent methanogenic community and characterized its constituents using RNA-iTAG. We obtained the DNA of an unknown environmental methanogen (BPM-1) from campus and compared its growth in coculture with known and unknown methanogens (*M. hungatei* and *M. formicicum*) and oxalate degraders (*O. formigenes*). We investigated the possibility of syntrophic growth between the oxalate degrader and methanogen through OD600 measurements of their respective growth curves and identified whether oxalate is used as an electron source or as a substrate for reduction in community degradation through C13 radiolabeling. To further understand oxalotrophy, we explored novel oxalotrophic pathways such as phototrophy in pond/soil communities. By growing cultures in defined oxalate media under IR light, we identified phototrophic oxalate-dependent communities/organisms.

Remote monitoring of inland water systems and their flux and gas transfer velocities in real-time
Luis Y. Serrano Laguna
Mentors: Woodward W. Fischer, Bryn Stewart, John S. Magyar, and Simon Andren

Literature has shown that inland water sources such as rivers tend to be large contributors to CO_2 flux. However, the mechanics behind the gas transfer between inland waters' surface and the atmosphere still remains difficult to monitor; current methods fail to account for the temporal and spatial variability inland water systems tend to experience due to natural processes that occur such as photosynthesis and respiration. This makes it difficult for researchers to obtain measurements representative of the entire system due to time constraints. This project aims to address these issues through the development of a robust sensor probe network for remote monitoring of CO_2 concentrations in water and potentially the gas transfer velocity in real time. The system consists of submerged probes monitoring the water dynamics of CO_2, temperature, and dissolved oxygen. A floating gas chamber will also be deployed for monitoring the flux of the water surface through a mass-transfer model at steady-state equilibrium. The embedded system behind the probes and gas chamber consists of a microcontroller capable of continuous transmission of sensor data through long range communication, allowing for real-time monitoring. A receiving hub will keep track of several deployed probes in different areas of the inland water systems to account for spatial variation and perform flux calculations for real-time gas transfer monitoring. This will improve our understanding of inland water system dynamics and offer a low-cost and scalable solution for large areas compared to other systems such as LI-COR.

Examining the effect of heterotrophic bacteria and viral lysis on the size and flux of diatom marine snow particles in the biological carbon pump
Elinor J. Holland
Mentors: Victoria J. Orphan and Jeremy E. Schreier

The biological carbon pump, the process by which atmospheric carbon dioxide is sequestered into the deep ocean through sinking marine snow particles, plays a major role in regulating climate on Earth. Diatoms, unicellular photosynthetic algae, account for ~15% of total carbon exported from the surface ocean making them a major component of the biological carbon pump. As these particles are formed and sink, they are colonized by heterotrophic bacteria. The mechanisms controlling the flux of these particles, however, remains unclear. Here, we examined the potential role bacteriophage play in modulating the size and flux of diatom marine snow particles through the lysis of associated bacteria. We generated diatom marine snow particles using model diatoms *Phaeodactylum tricornutum* (Pt) and *Chaetoceros muelleri* (Cm) in the presence or absence of heterotrophic bacteria and/or bacteriophage using natural communities or model isolates. Using the Malvern Mastersizer 3000E, we measured the size distribution of both the suspended planktonic particles and sedimented, dense particles. Preliminary results using natural bacterial and viral communities suggested contrasting results between the two diatoms. In Cm planktonic fractions, the addition of concentrated virus displayed a shift from small (1-10 um) to larger (100-1000 um) sized particles in both the presence or absence of a bacterial community. In Pt planktonic fractions, however, the addition of concentrated virus created >100 um sized particles that were not seen in any other treatment. These data suggest that diatom marine snow particle size distributions are community specific and can be affected by viruses alone.

Modeling sill deflation and fault slip during caldera collapse at Bárðarbunga, Iceland
Natalia M. Hernandez
Mentors: Elias Heimisson and Gabriele Benedetti

Caldera collapse occurs when magma is withdrawn from a shallow reservoir, resulting in the structural failure of the overlying rock. During the 2014 eruption of Bárðarbunga, magma migrated from beneath the caldera to feed the Holuhraun eruption, which triggered gradual collapse over weeks. This project investigates the mechanical interaction between magma withdrawal and ring fault slip by modeling surface deformation during this collapse. Using a symmetric model consisting of a deflating sill and slipping fault on MATLAB, the study roughly simulates surface displacements recorded by GPS. We estimated caldera geometry by fitting a circle around microearthquake locations along the system and constrained the sill to this boundary. Modeled displacements were compared to observations from GPS stations active during the collapse, proving successful reproduction of vertical and horizontal displacements. These results provide constraints on reservoir and fault parameters and offer insight into the mechanics of caldera collapse driven by distant eruptions. These constraints are then used to calculate the stresses transmitted to the fault from sill deflation to assess its stability and potential feedback between the magma withdrawal and fault slip.

Using Raman and optical spectroscopy to isolate the spectroscopic signatures of the rare earth elements
Stephen W. Goehringer
Mentor: George R. Rossman

Many modern technologies require an abundance of rare earth elements, yet few economically viable deposits have been identified. This project aims to improve our ability to discover new rare earth deposits by collecting detailed spectroscopic data on rare earth chemicals, and identifying/quantifying the unique spectroscopic signatures of the rare earth elements. We then analyzed an array of fluorite samples (a mineral prone to rare earth substitutions), and used our spectroscopic signatures to imply the concentrations of rare earth elements in the sample. We confirmed our results with an X-ray Fluorescence machine, demonstrating that this approach is a promising option for field exploration.

Development of an artificial urine standard for stable calcium isotope analysis for geochemical applications
Priscilla Boo
Mentors: François Tissot, Rebecca J. Ryan, and Theo J. Tacail

Calcium (Ca) isotopes in urine are rising in popularity as a non-invasive biomarker for bone mineral balance. However, there is currently no reference material that reflects the complexity of the urine matrix while also being appropriate for isotope work. This hinders inter- and intra-lab comparability and complicates troubleshooting across workflows. This project aims to develop and validate an artificial urine standard specifically for $\delta^{44/42}$Ca (‰) analysis by Multi-Collector Inductively Coupled Plasma-Mass Spectrometry (MC-ICP-MS) that is both biologically and geochemically robust. Two batches of standards were synthesized: one artificial urine standard and one matrix-only standard (without Ca). The validation of the artificial urine standard using matrix-only standard involved two main parts: (1) running multiplicates of the different aliquots of the artificial urine standard and (2) assessing how the urine matrix affects isotope measurements on the MC-ICPMS. The data shows that all the synthesized artificial urine produced homogenous $\delta^{44/42}$Ca values. The matrix-only standard spiked before the workflow showed the same $\delta^{44/42}$Ca ratios as the artificial urine standard and that the Ca recovery throughout the process was within error. Finally, the blank matrix-only standard yielded negligible $\delta^{44/42}$Ca values or quantifiable $\delta^{44/42}$Ca values.

Tracking the movement of the dust clump in the debris disc of Beta Pictoris

Polaris C. Hayes
Mentors: Konstantin Batygin and Yinuo Han

The Beta Pictoris debris disc system is notable for its extent and features, including its non-axial symmetry in the form of a localized "clump" of excess dust, centered at around 85 au from the star. Previous analysis by Han et al. (2023) using three epochs over 12 years found the clump to be likely stationary, statistically ruling out both Keplerian motion and 2:1 resonant motion with an outward-moving planet. In this study, we incorporate a new epoch of high-resolution observations from 2024, representing a 21-year time baseline to further constrain the clump's projected motion. Our methodology includes frame centering via 2D Gaussian fitting, mutual point-spread function (PSF) convolution across epochs, Markov Chain Monte Carlo modeling to identify a consistent spatial configuration, and linear displacement fitting to quantify motion. Tighter constraints on the clump's dynamics could help to inform its origin and provide implications of planetary formation in the disk, as well as provide key insights into the dynamical processes shaping young planetary systems and the frequency of giant impacts in their evolution.