Bayesian Updating of Uncertain Parameter Vectors by Sampling From an Auxiliary Dynamic System
Hanna Hultin
Mentors: James Beck and Thomas Catanach

Bayesian updating can be used to learn uncertain model parameter vectors with sensor data from a dynamic system. A fully probabilistic Bayesian model updating approach requires the evaluation of multidimensional integrals which usually cannot be done analytically. Instead sampling based numerical methods can be used, although high-dimensional problems are still challenging for current sampling methods. The aim of this project is to examine how to use theory from stochastic dynamics to generate samples from a high-dimensional distribution efficiently. This method, which we call the Langevin Monte Carlo method, should work well in higher dimensions because the samples naturally move to areas of high probability according to the stochastic dynamics. To reduce the unproductive computational effort during the settling-in period, as short settling time and low correlation as possible is sought. In this project, the method used to reduce the settling time is by choosing the damping and temperature schedule for a virtual annealing scheme.

Numerical Solver for the Linear Hamilton-Jacobi-Bellman Equation
Ulf Elis Stefansson
Mentors: John Doyle and Yoke Peng Leong

The Hamilton-Jacobi-Bellman equation provides globally optimal solutions to a wide range of control problems. However, algorithms obtaining such solutions typically exhibit the curse of dimensionality enabling calculations for just a moderate number of states. This paper presents a toolbox for solving a linear version of the Hamilton-Jacobi-Bellman equation. The curse of dimensionality is addressed using tensor decompositions, where the resulting algorithm scales linearly with the number of states in the system. Alternating least squares, the main algorithm in the toolbox, is investigated and improved. Examples illustrate the performance of the toolbox.

Investigating Multi-Epoch Spectral Variability in Quasars
Alison Dugas
Mentor: Matthew J. Graham

Various astrophysical processes can only be studied in the time domain, including the accretion of matter into black holes. Quasars vary in time at all wavelengths and are believed to be caused by supermassive black holes. The Catalina Real-time Transient Survey (CRTS) is the largest currently-operating open transient survey, and it has light curves for about 340,000 spectroscopically-confirmed quasars. The Sloan Digital Sky Survey (SDSS) has as many as three spectra for each of these objects, taken across about ten years. The aim of this project is to identify quasars with unusual spectra and highly variable light curves and investigate whether their spectra have also changed throughout time. We have developed a way to identify statistically deviant light curves, and have used this to find quasars that display variability both spectroscopically and in brightness.

Probing Quasar Physics With Variability and Machine Learning
Catalina-Ana Miritescu
Mentors: Matthew Graham and George Djorgovski

Quasars are cosmic objects which have long been known to be variable sources. Their variability is being monitored by digital sky surveys, the largest open time domain survey currently operating being the Catalina Real-time Transient Survey (CRTS). A new variability-based method has been developed to analyze variable objects: the Slepian Wavelet Variance (SWV). The SWV is a statistical characterization of a large set of time series (light curves). In this project, we used SWV on a subset of CRTS data to determine the general trend of each known subtype of quasars (classes determined spectroscopically) and to identify possible outliers. From the outliers identified, we selected as objects warranting further study the ones whose light curves had unusual appearance. Using the specific behaviors for each class determined from the subset, we can extend the search for objects of interest to the whole CRTS database.

Design of a Highly Efficient, Cost Effective Anode for Chlorine Evolution and Wastewater Treatment
Daniel Ocasio
Mentors: Michael Hoffmann and Yang Yang

Nearly 20% of the manufacturing expense of the Hoffmann group’s self-contained, photovoltaic-powered toilet and wastewater treatment system is contributed by the cost of the electrode array. This high expenditure is due largely to the current design of the IrO2 anode used within the wastewater electrolysis cell. In order to reduce this cost, an alternative anode design was proposed that replaces the costly IrO2 interlayer with a more affordable substance: RuO2. The anodes were prepared by repetitively brush coating Ru precursor onto pretreated conductive Ti sheets and annealing until a desired mass loading was achieved. Then an aqueous
A titanium glycolate complex was thermally decomposed onto the surface to provide stability. These anodes were then coupled with a stainless steel cathode and AgCl reference electrode in a single compartment electrolysis cell and electrochemically analyzed with potentiostatic methods for current efficiency, chlorine evolution rate, and reaction overpotential. Next, each anode was subjected to an accelerated life test operated at a high current in order to determine the stability. The most promising samples were then employed in wastewater electrolysis tests to observe their chemical oxygen demand (COD) and ammonium removal capabilities. Finally, a mechanistic study was performed in order to examine the pathway by which wastewater treatment is achieved. Overall, the best performing electrode design was comprised of

$$1.56 \times 10^{-6} \text{mol/cm}^2 \text{RuO}_2$$

and

$$3.76 \times 10^{-6} \text{mol/cm}^2 \text{TiO}_2.$$  

The results indicate that the cost-effective RuO2 electrode is even more efficient than the previous IrO2 design in terms of chlorine evolution and COD removal. However, no conclusion can yet be made on the stability of the new design until further testing is performed.

Environmental Context Dependent Memory in Virtual Reality

Ayaana Patel Sikora
Mentor: David M. Krum

As virtual reality technologies are increasingly being used in applications such as training and education, it is becoming crucial to understand the perceptual and psychological effects of virtual learning. Previously conducted research in human memory has identified the environmental context dependent memory effect, in which environmental stimuli are incidentally processed during learning and can later cue recall and improve memory performance. We are exploring how this effect plays a role in virtual learning. We have developed study protocols involving virtual reality environments and word recall tests to examine this effect, and we are currently validating our experimental infrastructure. We have also constructed virtual replicas of real world environments using a 3D laser scanner. These replicas will be used to test if virtual reality could evoke the environmental contexts for learning and later produce improved recall in the corresponding real world environments. We also plan additional studies to examine whether real world sensory cues, such as olfactory and auditory signals, could bleed in through the immersion and provide additional context. Understanding how human memory is affected by environmental contexts and simulated contextual cues could be beneficial to addressing learning and memory issues in domains such as eyewitness testimony, psychotherapy, and education.

Quantum Walk Frameworks and Quantum Speedup of Markov Mixing

Jeremy D. Bernstein
Mentors: Thomas Vidick and Stacey Jeffery

Algorithms based on random walks have a wide applicability: from problems in theoretical Computer Science to Google's PageRank algorithm. We investigate two frameworks for quantising algorithms on reversible Markov chains that confer polynomial speedup over the classical counterparts. The MNRS framework is based on the spectral properties of Markov chains, and the Belovs framework is based on the electric network interpretation.

In an effort to unify the frameworks, we rediscover a quantum algorithm for sampling from the stationary distributions of ergodic, reversible Markov chains due to Wocjan and Abeyesinghe. The algorithm makes use of phase estimation on the Szegedy walk operator to implement a reflection in the stationary distribution à la MNRS. The complexity is asymptotically better in the size of the spectral gap than both the classical power method and a quantum algorithm using adiabatic state generation due to Aharonov and Ta-Shma. We use this algorithm to compare the power of the Belovs and MNRS frameworks.

Fruit Flies Activity Recognition Using Decision Tree

Ruoqi Shen
Mentor: Yisong Yue

One technical challenge neuroscientists and biologists face is the fact that analyzing behavior requires analyzing large amount of video or tracking data. For example, currently there are thousands of hours of video on fruit fly behavior here at Caltech, and it is impossible for scientists to manually analyze this video. Machine learning is very promising because it can be used to develop an automated approach for animal behavior analysis. This project use decision tree to automatically detect behaviors such as lunge, tussle and other aggressive actions and copulation attempt, copulation and other courtship actions in fruit fly tracking data. I first use features from single frame to train models and then use features from multiple frames. I also train sliding window models and compare them with the frame-level prediction models.