2021 REU Project List

**Project 1: Deep Learning to Improve Ultrasound and Photoacoustic Image Quality**

**Mentor: Professor Muyinatu Bell**

**Project Description:**

Deep learning methods are capable of performing sophisticated tasks when applied to a myriad of artificial intelligent research fields. This project builds on our pioneering expertise to explore novel approaches that replace the inherently flawed beamforming step during ultrasound and photoacoustic image formation by applying deep learning directly to raw channel data. In ultrasound and photoacoustic imaging, the beamforming process is typically the first line of software defense against poor quality images.

**Role of REU Student:**

Implement simulations of acoustic wave propagation to create a sufficient training data set; train and test multiple network architectures; data analysis and interpretation

**Preferred Background & Skills:**

Programming experience in MATLAB and C/C++; experience with Keras and/or TensorFlow; familiarity with computer vision and basic deep learning techniques; experience with ultrasound imaging and would be helpful, but not required.

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**Project 2: Photoacoustic-Guided Surgery**

**Mentor: Professor Muyinatu Bell**

**Project Description:**

Photoacoustic imaging is an emerging technique that uses pulsed lasers to excite selected tissue and create an acoustic wave that is detected by ultrasound technology.  This project explores the use of photoacoustic imaging to detect blood vessels behind tissues during minimally invasive surgeries, such as neurosurgery, spinal fusion surgery, and gynecological surgeries like hysterectomy.

**Role of REU Student:**

Literature searches; phantom design and construction; perform experiments with *ex vivo* tissue; data analysis and interpretation; preparation of a photoacoustic imaging system for clinical studies; interact and interface with clinical partners at the Johns Hopkins Hospital

**Preferred Background & Skills:**

Ability to perform laboratory experiments and analyze results; programming experience in MATLAB; experience with ultrasound imaging, lasers, optics, and/or programming experience in C/C++ or Python would be helpful, but not required.

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**Project 3: Photoacoustic-Based Visual Serving of Surgical Tool Tips**

 **Mentor: Professor Muyinatu Bell**

**Project Description:**

In intraoperative settings, the presence of acoustic clutter and reflection artifacts from metallic surgical tools often reduces the effectiveness of ultrasound imaging and complicates the localization of surgical tool tips. This project explores an alternative approach to tool tracking and navigation in these challenging acoustic environments by augmenting ultrasound systems with a light source (to perform photoacoustic imaging) and a robot (to autonomously and robustly follow a surgical tool regardless of the tissue medium). The robotically controlled ultrasound probe will continuously visualize the location of the tool tip by segmenting and tracking photoacoustic signals generated from an optical fiber inside the tool.

**Role of REU Student:**

System validation in the presence of multiple tissue types; hands-on experiments with an integrated robotic-photoacoustic imaging system; data analysis and interpretation

**Preferred Background & Skills:**

Ability to perform laboratory experiments and analyze results; programming experience in MATLAB; programming experience in C/C++ and Python; experience with ultrasound imaging, lasers, and/or optics, would be helpful, but not required.

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**Project 4: Can a fish learn to ride a bicycle?**

**PI: Noah J. Cowan**

**Mentor: Yu Yang**

**Project Description:**

Animals adeptly learn new motor behaviors, such as walking, running, gymnastics, and even learn to control counter-intuitive dynamics like a skateboard or bicycle. To investigate now the nervous system does this, we are developing a method to see if a fish can "learn to ride a bicycle" -- that is, can a fish learn to control new dynamics? The glass-knifefish, *Eigenmannia virescens*, perform a refuge-tracking task in which a refuge (a plastic tube) is moved back and forth under computer control, and the fish swims forward and backward to remain hidden within the tube. We have developed a real time control system that allows us to generate dynamic movement of the refuge in relation to the fish's motion. In this way, we alter the sensory consequences of the fish's own movement in a closed-loop paradigm. For example, we can make the tube go backward when the fish goes forward, changing the way the fish must swim to remain hidden. Our hypothesis is that changes in locomotor dynamics will trigger adaptive responses in the fish's tracking controller. Further, we expect to observe a post-adaptation period, where the fish regains its original controller after the novel dynamics are removed. Preliminary results with sum-of-sines system identification support our hypothesis by exhibiting a decrease in fish’s gain in response to some frequency bands and recovering the gain when the “novel locomotion dynamics” are removed. The data suggests that we can trigger and monitor adaptation and post-adaptation responses of a fish by using closed-loop feedback control system.

**Role of REU Student:**The REU student will run new experiments with the fish, analyze data in Matlab and write up the results for presentation. A reasonable goal will be to present the work at the annual meeting of the Society of Integrative and Comparative Biology.

**Required Background & Skills:** Knowledge of linear algebra and differential equations, and proficiency with Matlab. No prior biological knowledge is required.

**Preferred Background & Skills:** A signals and systems or control systems course.

**Project 5: Haptic Feedback and Control for Upper-Limb Prosthetic Devices**

**Mentor: Professor Jeremy D. Brown**

**Project Description:**

Individuals with an upper-limb amputation generally have a choice between two types of prostheses: body-powered and externally-powered. Body powered prostheses use motion in the body to generate motion of the prosthetic gripper by means of a cable and harness system that connects the body to the device. In this way, body-powered prostheses feature inherent haptic feedback: what is felt in the gripper gets transmitted through the cable to the harness. Externally-powered prostheses come in many forms, however, most utilize electromyography (EMG) for controlling the prosthetic gripper. Since this control input is electrical, there is no mechanical connection between the body and the prosthetic gripper. Thus, myoelectric EMG-based prostheses do not feature haptic feedback and amputees who wear them are currently unable to feel many of the physical interactions between their prosthetic limb and the world around them. We have previously shown that prostheses with lower mechanical impedance allow for a high degree of naturalistic control, and that haptic force feedback of grip force provides more utility than vision in an object recognition task. This project seeks to build on these previous findings by investigating the entire sensorimotor control loop for upper-limb prostheses. The research objective of this project is to test the hypothesis that sensory feedback and control requirements for upper-limb prosthesis function will be task specific.

**Role of the student:**

With supportive mentorship, the REU student will lead the refinement and evaluation of our current mock upper-limb prosthesis experimental apparatus, which involves mechanical, electrical, and computational components. He or she will then work closely with clinical partners to design, conduct, and analyze a human-subject experiment to evaluate specific aspects of the overarching research hypothesis.

**Helpful Skills:**

Experience with CAD, Matlab, and/or C++ would be beneficial. Interest in working collaboratively with both engineering and clinical researchers. Mechatronic design experience and human-subject experiment experience would be helpful but are not required.

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**Project 6: Bimanual Haptic Feedback for Robotic Surgery Training**

**Mentor: Professor Jeremy D. Brown**

**Project Description:**

Robotic minimally invasive surgery (RMIS) has transformed surgical practice over the last decade; tele-operated robots like Intuitive Surgical’s da Vinci provide surgeons with vision and dexterity that are far better than traditional minimally invasive approaches. Current commercially available surgical robots, however, lack support for rich haptic (touch-based) feedback, prohibiting surgeons from directly feeling how hard they are pressing on tissue or pulling on sutures. Expert surgeons learn to compensate for this lack of haptic feedback by using vision to estimate the robot’s interactions with surrounding tissue. Yet, moving from novice proficiency to that of an expert often takes a long time. We have previously demonstrated that tactile feedback of the force magnitude applied by the surgical instruments during training helps trainees produce less force with the robot, even after the feedback is removed. This project seeks to build on these previous findings by refining and evaluating a bimanual haptic feedback system that produces a squeezing sensation on the trainee’s two wrists in proportion to the forces they produce with the left and right surgical robotic instruments. The research objective of this project is to test the hypothesis that this bimanual haptic feedback will accelerate the learning curve of trainees learning to perform robotic surgery. In addition, this project seeks to use haptic signals to objectively measure and eventually improve skill at robotic surgery.

**Role of the student:**

With supportive mentorship, the REU student will lead the refinement and evaluation of our current haptic feedback system, which involves mechanical, electrical, and computational components. He or she will then work closely with clinical partners to select clinically appropriate training tasks and will design, conduct, and analyze a human-subject experiment to evaluate the system.

**Helpful Skills:**

Experience with CAD, Matlab, and/or Python would be beneficial. Interest in machine learning and in working collaboratively with both engineering and clinical researchers. Mechatronic design experience and human-subject experiment experience would be helpful but are not required.

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**Project 7: Extracting Markers of Emotion in Human Speech**

**Mentor: Professor Archana Venkataraman**

**Project Description:**

Emotion is the cornerstone of human social interactions, yet it still eludes modern-day Artificial Intelligence. One of the biggest roadblocks to developing emotionally aware AI is that we lack a comprehensive model of emotional speech. This project aims to bridge this gap by isolating the features of human speech that convey emotion. These features can be linked to the underlying signal characteristics (pitch, intensity, rhythm), the linguistic content, and speaking style. This project will also link perceptual variability to underlying demographic factors to quantify the “emotional salience” of each utterance.

**Role of the student:**

The goals of this project include but are not limited to:

1. Develop and implement machine learning algorithms for emotion recognition; this task may require the use of deep learning architectures
2. Identify statistical differences in human emotional perception based on gender, sentence structure, and linguistic content.

**Helpful Skills:**

Students should have a solid mathematical foundation (calculus, linear algebra, and statistics) and experience with MATLAB or Python. Knowledge of signal processing and machine learning is preferred but not required.

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**Project 8: Predicting Neurological Deficit from Functional MRI Data**

**Mentor: Professor Archana Venkataraman**

**Project Description:**

Neurological and neuropsychiatric disorders affect millions of people worldwide and carry a tremendous societal cost. Despite ongoing efforts, we have a bare-bones understanding of these disorders, and hence, a limited ability to treat them. The goal of this project is to identify predictive biomarkers of schizophrenia and spinal cord injury from functional MRI data. Students will use and potentially refine a machine learning algorithm that has been developed in the lab to predict behavioral symptoms and genetic risk. The project will involve close collaborations on the medical campus.

**Role of the student:**

The goals of this project include but are not limited to:

1. Adapt our machine learning pipeline to predict the level of paralysis in spinal cord injury using fMRI data.
2. Refine our existing algorithms to correlate brain activation to genetic risk for schizophrenia

**Helpful Skills:** Students should have a solid mathematical foundation (calculus, linear algebra, and statistics) and experience with MATLAB or Python. Knowledge of signal processing and machine learning is preferred but not required.

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# Project 9: Robotic System for Mosquito DissectionMentors: Professor Russell Taylor and Professor Iulian Iordachita

**Project Description:**

We have an ongoing collaboration with Sanaria, Inc. to develop a robotic system for extracting salivary glands from *anopheles* mosquitoes, as part of a manufacturing process for a clinically effective malaria vaccine that is being developed by Sanaria. This project combines computer vision, real time programming, robotics, and novel mechanical design aspects. The specific task(s) will depend on the student(s) background, but may include: 1) real time computer vision; 2) machine learning for vision; 3) real time robot programming; 4) mechanical design; 5) system testing and evaluation. Depending on the project and progress, there will be opportunities to participate in academic publication and possible further patenting.

**Preferred Background Skills:**

For software, robot programming, or vision projects, the student(s) should have experience with Python. In addition, experience with vision and/or deep learning will be needed for vision-oriented projects. For mechanical design, students should have significant experience with mechatronic design, CAD, 3D printing and other fabrication processes. Experience with computer interfaces and low-level control (e.g., with Arduino-type subsystems) may also be useful.

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# Project 10: Instrumentation and steady-hand control for new robot for head-and-neck surgeryMentor: Professor Russell Taylor

**Description**:

We have an active collaboration with Galen Robotics, which is commercializing a “steady hand” robot developed in our laboratory for head-and-neck microsurgery.   In “steady hand” control, both the surgeon and the robot hold the surgical instrument. The robot senses forces exerted by the surgeon on the tool and moves to comply.  Since the motion is actually made by the robot, there is no hand tremor, the motion is very precise, and “virtual fixtures” may be implemented to enhance safety or otherwise improve the task.  Potential applications include endoscopic sinus surgery, transphenoidal neurosurgery, laryngeal surgery, otologic surgery, and open microsurgery. While the company is developing the clinical version of the robot, we have active on-going research to develop novel applications for the system.

Possible projects include:

* Development of “phantoms” (anatomic models) for evaluation of the robot in realistic surgical applications.
* User studies comparing surgeon performance with/without robotic assistance on suitable artificial phantoms.
* Optimization of steady-hand control and development of virtual fixtures for a specific surgical application
* Design of instrument adapters for the robot
* Developing interfaces to surgical navigation software

**Required Skills:**

The student should have a background in biomedical instrumentation and an interest in developing clinically usable instruments and devices for surgery. Specific skills will depend on the project chosen. Experience in at least one of robotics, mechanical engineering, and C/C++ programming is important. Similarly, experience in statistical methods for reducing experimental data would be desirable.

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# Project 11: Accuracy Compensation for “Steady Hand” Cooperatively Controlled RobotsMentor: Professor Russell Taylor

**Description:**

Many of our surgical robots are cooperatively controlled.  In this form of robot control, both the robot and a human user (e.g., a surgeon) hold the tool.  A force sensor in the robot’s tool holder senses forces exerted by the human on the tool and moves to comply.  Because the robot is doing the moving, there is no hand tremor, and the robot’s motion may be otherwise constrained by virtual fixtures to enforce safety barriers or otherwise provide guidance for the robot.  However, any robot mechanism has some small amount of compliance, which can affect accuracy depending on how much force is exerted by the human on the tool.  In this project, the student will use existing instrumentation in our lab to measure the displacement of a robot-held tool as various forces are exerted on the tool and develop mathematical models for the compliance.  The student will then use these models to compensate for the compliance in order to assist the human place the tool accurately on predefine targets.  We anticipate that the results will lead to joint publications involving the REU student as a co-author.

**Required Skills:**

The student should be familiar with basic laboratory skills, have a solid mathematical background, and should be familiar with computer programming.  Familiarity with C++ would be a definite plus, but much of the programming work can likely be done in MATLAB or Python.

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**Project 12: Software Framework for Research in Semi-Autonomous Teleoperation**

**Mentor: Professors Peter Kazanzides and Russell Taylor**

**Project Description:**

We have developed an open source hardware and software framework to turn retired da Vinci surgical robots into research platforms (da Vinci Research Kit, dVRK) and have disseminated it to 35 institutions around the world. The goal of this project is to contribute to the advancement of this research infrastructure.

**Role of the student:**

The specific task will take into account the student’s background and interests, but may be one of the following: (1) 3D user interface software framework, (2) data collection tools and protocols to support machine learning, (3) integration of alternative input devices and/or robots, or (4) development of dynamic models and simulators.

**Helpful Skills:**

Student should have experience with at least one of the following programming environments: C/C++, Python, ROS.

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**Project 13:** Colloidal Quantum Dot-Based Field Effect Transistors for Photo-sensing and Materials Characterization

**PI:** Susanna M. Thon

**Mentor:** Sreyas Chintapalli

**Project Description:** Colloidal quantum dots (CQDs) are promising materials for technologies such as solar cells, infrared photodetectors, and flexible electronics. As such, they can be incorporated into a variety of device types, including field effect transistors, which can serve as both photo-sensors and platforms for characterizing basic CQD film optoelectronic properties. The aim of this project is to fabricate, test, and optimize a robust CQD-based field effect transistor architecture. The transistors will be used as a photosensing platform and to measure CQD solar cell film properties. The project will include chemical synthesis, device fabrication, and optical/electronic testing components.

**Role of REU Student:**The REU student will be in charge of fabricating the CQD field effect transistors and iterating on their design. Additionally, the REU student will assist graduate students with colloidal materials synthesis, optoelectronic device characterization, and data analysis.

**Required Background & Skills:** Familiarity with Matlab.

**Preferred Background & Skills:** Thin-film deposition, photolithography, and processing skills, and some experience or comfort level with wet chemistry techniques are desirable but not required. All lab skills will be taught as-needed.

**Project 14:** Design of a Small Legged Robot to Traverse a Field of Multiple Types of Large Obstacles

**PI:** Chen Li

**Mentor:** Ratan Othayoth, Yaqing Wang, Qihan Xuan

**Project Description:**

A main challenge that has prevented robots from moving as well as animals in complex terrain is the relative lack of understanding of how to make use of physical interaction between animals and robots (locomotors) and the surrounding terrain. Currently the primary approach of robot locomotion in complex environments is to avoid obstacles (e.g., self-driving cars) simply relying on environment geometry. However, for robots dynamically moving through complex terrain with many large obstacles, such as forest floor or earthquake rubble, it is impossible to always avoid obstacles. Instead, making use of physical interaction with obstacles becomes essential. This project will integrate insights from our lab’s work over the past few years to design an initial prototype of a small legged robot that can traverse a field of multiple types of large obstacles.

**Role of REU Student:**

The REU student will design the robot with the supervision of the PI and PhD students.

**Required Background & Skills:** Strong mechatronics skills, including CAD design, 3D printing, machining, microcontroller programming, experience using sensors (IMU/force sensors/cameras) and actuators (servo motors/linear actuators).

**Preferred Background & Skills:** integrating sensors (IMU/force sensors/cameras) and actuators (servo motors/linear actuators), automation, feedback control, C++, Robot Operating System, circuit design, signal communication.

For more information, visit <https://li.me.jhu.edu/>.

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**Project 15: Telerobotic System for Satellite Servicing**

**Mentor: Professors Peter Kazanzides, Louis Whitcomb and Simon Leonard**

**Project Description:**

With some satellites entering their waning years, the space industry is facing the challenge of either replacing these expensive assets or to develop the technology to repair, refuel and service the existing fleet. Our goal is to perform robotic on-orbit servicing under ground-based supervisory control of human operators to perform tasks in the presence of uncertainty and time delay of several seconds. We have successfully demonstrated telerobotic removal of the insulating blanket flap that covers the spacecraft’s fuel access port, in ground-based testing with software-imposed time delays of several seconds.

**Role of the student:**

The student will assist with this ongoing research, including the development of enhancements to the mixed reality user interface, experimental studies, and extension to other telerobotic operations in space.

**Helpful Skills:**

Ability to implement software in C/C++, familiarity with ROS, good lab skills to assist with experiment setup, and ability to analyze experimental results.

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**Project 16: Mathematical and Scientific Foundations of Deep Learning**

**Mentors: René Vidal, Soledad Villar, Joshua Vogelstein, Mauro Maggionni**

**Project Description:**

Several REU opportunities are available as part of an [NSF-Simons Research Collaboration on the Mathematical and Scientific Foundations of Deep Learning](https://nam02.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.nsf.gov%2Fnews%2Fspecial_reports%2Fannouncements%2F082520.jsp&data=02%7C01%7Cmtully4%40jhu.edu%7Cb4ba7a84d5f9484b2c4f08d850559852%7C9fa4f438b1e6473b803f86f8aedf0dec%7C0%7C0%7C637347675836932856&sdata=ijHBudItO0eDQrDa4pk6tJ7jmnSW1si5lkNjMQ96z9Y%3D&reserved=0) (MoDL). The collaboration is entitled Hierarchical, Expressive, Optimal, Robust, and Interpretable NETworks (THEORINET) and involves multiple researchers from Johns Hopkins University, Duke University, Stanford University, the University of Pennsylvania and the University of California at Berkeley. The goal of the project is to develop a mathematical, statistical and computational framework that helps explain the success of current network architectures, understand its pitfalls, and guide the design of novel architectures with guaranteed confidence, robustness, interpretability, optimality, and transferability. For more details, please see https://www.minds.jhu.edu/theorinet/

**Project Goals:** REU opportunities are available in the following broad areas:

1. **Analysis**: Study properties of deep neural networks, such as expressivity, interpretability, confidence, fairness and robustness using principles from approximation theory, information theory, statistical inference, and robust control.
2. **Learning**: Design and analyze learning algorithms with guaranteed convergence, optimality and generalization properties using principles from dynamical systems, non-convex and stochastic optimization, statistical learning theory, adaptive control, and high-dimensional statistics.
3. **Design**: Design and learn network architectures that capture algebraic, geometric and graph structures in both the data and the task using principles from algebra, geometry, topology, graph theory and optimization.
4. **Transfer**: Design and study representations suitable for learning from and transferring to multiple tasks using principles from multiscale analysis and modeling, reinforcement learning, and Markov decision processes.

**Role of the Student:**

The student will work with PhD students to develop theoretical and empirical approaches to analyze deep network properties. The student will learn necessary background knowledge in statistics, machine learning and optimization to contribute to this research. The student will gain experience implementing small and medium-scale deep networks using popular deep learning frameworks and evaluating their behavior. The student will present his or her work to other students and professors and will potentially be able to publish his or her research on conferences and journals.

**Helpful Skills:**

Strong background in statistics, machine learning and optimization and experience in MATLAB/Python coding are required.

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**Project 17: Characterizing Semantic Information Content in Multimodal Data**

**Mentor: Professor René Vidal, Donald Geman and Benjamin Haeffele**

**Project Description:**

In 1948, Shannon published his famous paper “A Mathematical Theory of Communication”, which laid the foundations of information theory and led to a revolution in communication technologies. Shannon's fundamental contribution was to provide a precise way by which information could be represented, quantified and transmitted. Critical to Shannon's ideas was the notion that the semantic content of a signal is irrelevant for transmission because any signal (text, audio, image, video) can be converted into bits, transmitted, and then reconstructed by the receiver. However, classical measures of information, such as Shannon entropy, can be sub-optimal for tasks other than transmission. For example, understanding the “meaning” of a sentence is critical for machine translation. This motivates several foundational questions: How can we quantify which data features of a given modality are most relevant for a task? How can we assess which modalities are most relevant for a task? What is the “inherent” complexity of a learning task, so as to compare one task with another?

**Project Goals:**

The goals of this project are to: (1) develop measures of information that take the signal semantics into account; (2) design a computational framework with efficient algorithms to compute these measures; (3) deploy the framework to assess the semantic information in data for learning tasks in practically relevant settings. The approach to defining semantic information is based on defining a large set of semantic queries that are relevant for a task. For example, “is there a car in the image”, “is there a person in the image”, “is the person carrying a suitcase”. Then, semantic information is defined as the minimum expected number of questions that are needed to solve the task. The computation of the minimum number of questions is achieved by playing a 20 questions game, where one chooses one question at a time in order of information gain. The implementation of this framework requires learning probabilistic models that relate data to queries and queries to task. In this project, we plan to develop methods that combine variational autoencoders and reinforcement learning.

**Role of the Student:**

The student will work with PhD students and Postdocs, having the opportunity to learn modern research methods in deep generative models for machine learning and computer vision. The student will implement code for training variational autoencoders and reinforcement in Python, and run them against real datasets. The student will present his or her work to other graduate students and professors and will potentially be able to publish the research in conferences and journals. As part of the group, the student will experience first-hand a rigorous and rewarding research environment.

**Helpful Skills:**

A strong background in probability, statistics, machine learning and computer vision and working experience in Python or MATLAB are required.

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**Project 18: Robustness of Deep Networks to Adversarial Attacks**

**Mentors: René Vidal, Mahyar Fazlyab, and Jeremias Sulam**

**Project Description:**

While neural networks haveachieved high performance in different learning tasks such as classification, localization and detection of objects in images and video, their accuracy drops significantly in the presence of small adversarial perturbations to the input data. Since such adversarial perturbations are imperceptible, detecting their presence in a dataset can be very difficult. This is a critical issue, since these perturbations can cause significant security risks in deploying neural networks in real world applications. This issue has motivated research in adversarial learning, which aims defend deep networks against adversarial attacks, e.g., by detecting that an attack has occurred, or by training networks with adversarial examples. However, so far research on adversarial learning has followed a cat and mouse game between attackers and defenders where attacks are proposed, they are mitigated by new defenses, and subsequently new attacks are proposed that break earlier defenses, and so on. This motivates the need for provable defenses that can theoretically guarantee the robustness of deep networks to small perturbations, as well as methods for detecting when an attack has occurred and which type of attack it is. Moreover, there is a need for understanding whether there are conditions under which no better attacks or defenses can be proposed.

**Project Goals:**

The goals of this work are to

1. Develop principled methods for reverse-engineering attacks based on block-sparsity. For example, assume we are given data from multiple classes (e.g., images of faces from multiple individuals) as well as a family of attacks (e.g., L1-bounded, L-2 bounded, patch-based attacks). Can we determine both the class as well as the attack type via block-sparse reconstruction, where each block corresponds to a different attack type?
2. Rigorously analyze and define measures of robustness in terms of the representations learnt by a DNN. For example, the Lypchitz constant or the restricted isometry constant of network layers, or the encoding gap of sparse encoding layers.
3. Use these measures to obtain insights towards building principled defenses for deep networks. For example, can we do adversarial training subject to robustness constraints?
4. Understand whether there are conditions under which attacks and defenses form a Nash equilibrium, so that no better attacks or defenses can be proposed. This requires formulating a game-theoretic approach to studying attacks and defenses

**Role of the Student:**

The student will work with PhD students and Postdocs, having the opportunity to learn modern research methods in deep generative models for machine learning and computer vision. The student will implement code for training variational autoencoders and reinforcement in Python, and run them against real datasets. The student will present his or her work to other graduate students and professors and will potentially be able to publish the research in conferences and journals. As part of the group, the student will experience first-hand a rigorous and rewarding research environment.

**Helpful Skills:**

A strong background in probability, statistics, machine learning and computer vision and working experience in Python or MATLAB are required.

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**Project 19: Subspace Clustering**

**Mentors: René Vidal and Benjamin Haeffele**

**Project Description:**

Subspace clustering is an important problem in machine learning with many applications in computer vision, such as clustering face images and segmenting multiple moving objects in a video. Given a set of data points drawn from multiple subspaces, the goal of subspace clustering is to simultaneously cluster the data into the subspaces and fit a subspace to each group. The Vision Lab has worked extensively on this topic and has developed geometric approaches such as Generalized Principal Component Analysis, spectral clustering approaches such as Sparse Subspace Clustering, and non-convex optimization approaches such as Dual Principal Component Analysis.The goal of the project is to further improve the algorithms for subspace clustering.

**Project Goals:**

Possible research directions include:

* Develop scalable algorithms that can handle data with millions of samples.
* Develop algorithms that can effectively deal with class-imbalanced data and improve clustering accuracy.
* Develop algorithms that are able to deal with missing entries in the data.
* Develop algorithms that learn a data affinity that is specifically designed for spectral clustering.
* Develop algorithms than can effectively deal with data points that are drawn from high relative dimensional subspaces, e.g. hyperplanes.
* Develop algorithms based on non-convex matrix factorization. These methods are often highly scalable and robust but are more difficult to optimize.
* Extend current algorithms so that they can account for nonlinear structures in data. In particular, one of the approaches is to jointly learn a feature representation using deep neural networks and apply subspace clustering.

**Role of the student:**

The student will work with PhD students to develop novel algorithms for subspace clustering. The student will implement code for these algorithms as well as test them on several databases. The student will learn necessary background knowledge in machine learning, computer vision, compressed sensing, optimization, and will read research papers on subspace clustering. Moreover, the student will implement novel algorithms in MATLAB/Python using different datasets. The student will present his or her work to other graduate students and professors and will potentially be able to publish the research in computer vision conferences and journals. As part of the group, the student will experience first-hand a rigorous and rewarding research environment.

**Helpful Skills:**

A strong background in linear algebra, optimization, and experience in MATLAB/Python coding are required.

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**Project 20: Analysis of Algorithms for Training Deep Neural Networks**

**Mentor: René Vidal and Benjamin Haeffele**

**Project Description:**

Deep learning based methods have replaced traditional machine learning algorithms as the state-of-the-art in nearly every problem domain. However, our understanding of why these methods are so successful is still very limited. Why is it that bigger networks always seem to generalize better? How is stochastic gradient descent able to converge to networks with zero loss, despite the non-convexity of the learning problem? What explains the success of certain design innovations over others, e.g. rectified linear activation and batch normalization? An important goal of ongoing research in the field is to begin to address some of these puzzles.

**Project Goals:**

Possible research directions include:

* Analyze optimization and generalization properties of various training methods, such as dropout, dropconnect, dropblock, and batch normalization. For example, what are their implicit regularization properties and inductive biases?
* Analyze optimization and generalization properties of gradient flow and gradient descent for overparametrized models. For example, can one achieve implicit acceleration of the optimization algorithm via overparametrization?
* Analyze new optimization algorithms emerging from the discretization of dynamical systems, such as Relativistic Gradient Descent. For example, derive convergence rates for certain classes of functions.

**Role of the student:**

The student will work with PhD students to develop empirical and theoretical approaches to probe the high-dimensional deep learning optimization landscape. The student will learn necessary background knowledge in machine learning and optimization to contribute to this research. The student will gain experience implementing small and medium-scale deep networks using popular deep learning frameworks and evaluating their behavior. The student will present his or her work to other graduate students and professors and will potentially be able to publish the research in machine learning conferences and journals. As part of the group, the student will experience first-hand a rigorous and rewarding research environment.

**Helpful Skills:**

A strong background in linear algebra, optimization, and experience in MATLAB/Python coding are required.

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**Project 21: Activity Recognition**

**Mentor: René Vidal**

**Project Description:**

The human visual system is exquisitely sensitive to an enormous range of human movements. We can differentiate between simple motions (left leg up vs. right hand down), actions (walking vs. running) and activities (making a sandwich vs. making a pancake). Recently, significant progress has been made in automatically recognizing human activities in videos. Such advances have been made possible by the discovery of powerful video descriptors and the development of advanced classification techniques. With the advent of deep learning, performance in simple tasks, such as action classification, has been further improved. However, performance in recently released large-scale video datasets depicting a variety of complex human activities in untrimmed videos is well below human performance for most activity recognition methods, since scaling to thousands of videos and hundreds of action classes as well as recognizing actions in real, unstructured environments is particularly challenging.

**Project Goals:**

The goal of this project is to develop algorithms for recognizing human actions in unstructured and dynamically changing environments. An automatic system for human activity recognition is of particular interest in applications such as surveillance, physical therapy rehabilitation, behavioral intervention systems, surgical skill evaluation, etc. In developing such systems, one typically faces problems such as, designing models to efficiently represent actions (feature extraction), classification of short pre-segmented clips, and spatial and temporal localization of actions (segmentation). In this project, we are especially interested in designing novel activity recognition algorithms that also exploit contextual information in scenes (e.g., via modeling each image or short clip as an attributed graph that captures object interactions). This requires the design of novel graph-based action representations in videos, efficient mechanisms for data processing and fusion, and the design of appropriate discriminative metrics for learning.

**Role of the student:**

The student will work alongside PhD students and develop novel algorithms for activity recognition tasks, such as fine-grained temporal activity segmentation and recognition and/or action detection/localization. The student will implement code for these algorithms as well as test them on several benchmark datasets. The student will read research papers on activity recognition and time-series modeling, and will learn new techniques to solve the above problems. Moreover, the student will implement novel algorithms in Python (MATLAB/C++) and become familiar with several computer vision and machine learning concepts. The student will present his or her work to other graduate students and professors and will potentially be able to publish the research in computer vision conferences and journals. As part of the group, the student will experience first-hand a rigorous and rewarding research environment.

**Helpful Skills:**

Experience in programming in programming (Python/MATLAB/C++) and familiarity with computer vision and basic machine learning techniques (such as Support Vector Machines, Conditional Random Fields, Hidden Markov Models and Neural Networks) are required.

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**Project 22: Accelerated Non-Convex Optimization**

**Mentor: René Vidal**

**Project Description:**

Optimization is at the core of almost every problem in machine learning and statistics. Modern applications require minimizing high dimensional functions for problems that may have polynomial complexity on the number of data points, imposing severe limits on the scalability of standard methods, such as gradient descent or other first order methods. In the 1980's Nesterov proposed a method to accelerate gradient descent which provably attains the fastest convergence possible under general assumptions, and since then this technique has been applied to several other first order algorithms. Nevertheless, the mechanism behind acceleration is still considered not well understood. Our group has recently obtained several promising results in connection to continuous dynamical systems, providing a unified perspective on acceleration methods. Moreover, from such connections, new algorithms were obtained.

**Project Goals:**

We want to understand known and some of the new accelerated algorithms obtained in connection to continuous dynamical systems in convex and possibly nonconvex settings. These methods will be applied to some problems of interest in machine learning such as subspace clustering, matrix factorization, matrix completion, or others. We aim at making solution methods to these problems faster and more scalable.

**Role of the student:**

The student will work with PhD students and Postdocs, having the opportunity to learn modern research methods in optimization for machine learning and dynamical systems, besides background material in machine learning, subspace clustering, and matrix completion. The student will implement code for accelerated optimization algorithms in Python, and run them against real datasets. The student will present his or her work to other graduate students and professors and will potentially be able to publish the research in conferences and journals. As part of the group, the student will experience first-hand a rigorous and rewarding research environment.

**Helpful Skills:**

A strong background in undergraduate mathematics and working experience in Python or MATLAB are required.

**Project 23: Feature Computation Methods in Optical Coherence Tomography Angiography**

**Mentors: Dr. Jerry Prince, Yihao Liu**

**Project Description:**

Retinal optical coherence tomography (OCT) is becoming an important tool in the diagnosis and management of neurological diseases. OCT angiography (OCTA), a new tool based on the same underlying technology, is proving to be a rich source of data on the condition of the vessels in the retina. It is challenging however, however, to compute accurate and reproducible image features from these images.

**Role of the REU Student:** The REU student will investigate new features that can be computed from OCTA data and will analyze the reliability of these computed features.

**Preferred Skills:** Basic image processing, Matlab, Python, and prior exposure to deep convolutional neural networks.

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**Project 24. Assessment of Magnetic Resonance Image Harmonization Approaches**

**Mentors: Dr. Jerry Prince, Lianrui Zuo**

**Project Description:**

Magnetic resonance (MR) images do not have a standardized intensity scale, which means that it is hard to compare images that are acquired at different times or on different scanners. This impedes best use of MRI both for clinical assessment of changes in a given patient and for scientific research across populations. We have been developing post-processing methods for so-called MRI harmonization using deep networks. While the basic theory and preliminary network architectures have been developed for different harmonization approaches, there is a need to evaluate their efficacy on various data sets.

**Role of the REU Student:** The REU student will run various MRI harmonization algorithms on publicly available MR datasets. Based on the resulting data, the REU student will analyze both the networks and their results using statistics and visualization to help evaluate and optimize the harmonization approaches.

**Preferred Skills:** Basic image processing, Python, and prior exposure to deep convolutional neural networks.

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**Project 25: Autonomous Quadcopter Flying and Swarming**

**PI: Prof. Enrique Mallada**

**Mentor: Yue Shen**

**Resources:**[**https://store.bitcraze.io**](https://nam02.safelinks.protection.outlook.com/?url=https%3A%2F%2Fstore.bitcraze.io%2F&data=04%7C01%7Cdwalte10%40jhu.edu%7C6a9210a5d51442e4291908d8aac992f8%7C9fa4f438b1e6473b803f86f8aedf0dec%7C0%7C0%7C637447130017716586%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C1000&sdata=5HyqcGDbUIXNerkIVf9OG88NsWaYrX026imgrPCjFh4%3D&reserved=0)

**Project Description:**

The recent confluence of control, robotics, and machine learning has led to algorithms with the capacity for dexterous maneuvering and sophisticated coordination. However, existing learning techniques require massive computation in offline/virtual environments. Our lab broadly aims to develop learning algorithms suitable for training in the physical environment with safety guarantees. With this aim, we seek to build a validation platform for testing algorithms for autonomous systems developed by the lab. In particular, this project aims to create a testing platform for testing autonomous quadcopter flying and swarming.

**Role of REU Student:**

The student will assist with several tasks developing and testing algorithms for quadcopter swarm coordination.

**Preferred Background & Skills:**

The student should have technical experience in calculus, differential equations, and preferably control. The student should have practical experience with at least one of the following programming environments: C/C++, Python, ROS.

**Project 26: Autonomous Car Racing**

**PI: Prof. Enrique Mallada**

**Mentor: Tianqi Zheng**

**Resources:**[**https://f1tenth.org**](https://nam02.safelinks.protection.outlook.com/?url=https%3A%2F%2Ff1tenth.org%2F&data=04%7C01%7Cdwalte10%40jhu.edu%7C6a9210a5d51442e4291908d8aac992f8%7C9fa4f438b1e6473b803f86f8aedf0dec%7C0%7C0%7C637447130017726581%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C1000&sdata=AavqJCF2FUFmoIoBEp5EgqXGJcnn2Lg3zZUSmyCnKeM%3D&reserved=0)

**Project Description:**

The recent confluence of control, robotics, and machine learning has led to algorithms with the capacity for dexterous maneuvering and sophisticated coordination. However, existing learning techniques require massive computation in offline/virtual environments. Our lab broadly aims to develop learning algorithms suitable for training in the physical environment with safety guarantees. With this aim, we seek to build a validation platform for testing algorithms for autonomous systems developed by the lab. In particular, this project aims to create a testing platform for testing autonomous car racing.

**Role of REU Student:**

The student will assist with several tasks including, hardware assembly, algorithm development,  and testing and validation.

**Preferred Background & Skills:**

The student should have technical experience in calculus, differential equations, and preferably control. The student should have practical experience with at least one of the following programming environments: C/C++, Python, ROS.