1. **Cerebellum Parcellation and Data Analysis of the Baltimore Longitudinal Study of Aging**
   Mentors: Dr. Jerry Prince, Shuo Han

   Description: The aim of this project is to run an existing cerebellum parcellation algorithm on a cohort of healthy aging controls. The project will establish normative estimates of volumes for various regions of the cerebellum during the aging process. The project is an opportunity to learn about the anatomy of core portion of the human brain while being engaged in a cutting edge research project.

   Role of the REU Student: The REU student will use statistical methods to first determine whether there are algorithm failures in the processed data. The student will then look for relationships in the data that may relate to cognitive decline.

   Preferred Skills: Matlab, Java, and basic image processing

2. **Development of Features for Segmentation & Registration of OCT Data**
   Mentors: Dr. Jerry Prince, Yufan He

   Description: Retinal optical coherence tomography (OCT) is proving to be an important tool in the diagnosis and management of neurological diseases. Currently, algorithms that are used to derive quantitative measures from OCT scanners are very much dependent on the scanner that is used. New features that are scanner indendent could improve the segmentation and registration of these data.

   Role of the REU Student: The REU student will investigate new features that are intended to be scanner independent and work on their incorporation in existing segmentation software.

   Preferred Skills: Basic image processing and Matlab

3. **Image-Based Biomechanics**
   Mentors: Dr. Jerry Prince, Dr. A. David Gomez

   Description: The project involves imaging the tongue during both normal and abnormal speech. Special magnetic resonance images (MRI) are acquired and analyzed both to determine the shape and the motion of the tongue. The goal is to implement, verify, and validate a technique for integration of image-based motion estimation and solid modeling of soft tissues.

   Role of the REU Student: The REU student will learn the basic concepts of mechanical modeling and then use MRI image information to compare simulated results to experimental dynamic data.

4. **Active Sensing in Biological Systems**
Mentor: Noah Cowan

Description: Active Sensing is the expenditure of energy---often in the form of movement---for the purpose of sensing. For example, when you sense the texture of an object, versus estimating its weight, you perform different hand motions. These specialized "active" hand movements match the properties of the very different types of sensory receptors used for each specific task. Our goal is to analyze such active sensing behavior in uniquely suited animal, the weakly electric fish (Fig. 1A). These fish produce and detect electric fields (i.e. "electrical sonar"). This fish perform a "hiding behavior" where they swim back and forth to stay hidden inside the a refuge (Fig. 1B). In the dark, they "shimmy" backward and forward (analogous to moving your hand on a surface) to enhance the sensory input to their electrical sensors (Fig. 1C). Our goal is to develop quantitative mathematical models of active sensing so that we can translate the ideas of active sensing in a rigorous way, into algorithms that could be implemented by a robotic system.

Role of the student: The REU student will be involved in biological experimentation using our custom-real-time, closed loop experimental system. In addition he or she will perform data analysis, system programming, and hopefully mathematical modeling of active sensing behavior.

Background Skills:
Undergraduate training in linear algebra and differential equations. Some knowledge of dynamical systems and control theory is highly desirable. Also, knowledge of Matlab or another language (C, C++, Python). No specific experimental background in biological systems is required, but a lack of fear of getting into the lab (with mentorship) and performing non-invasive behavior experiments on live animals (specifically, fish) is essential.

Preferred Skills: Matlab, C++, and basic image processing or mechanics

5. **Telerobotic System for Satellite Servicing**
Mentors: Louis Whitcomb and Simon Leonard, Peter Kazanzides

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 developed an information-rich telemanipulation environment, based on the master console of a customized da Vinci surgical robot, together with a set of tools specifically designed for in-orbit manipulation and servicing of space hardware. We have successfully demonstrated telerobotic removal of the insulating blanket flap that covers the spacecraft's fuel access port, under software-imposed time delays of several seconds. The student will assist with this ongoing research, including the development of enhancements to the mixed reality user interface, experimental studies, and possibly extension to other telerobotic servicing operations.

Preferred Background 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.

6. **Software Framework for Research in Semi-Autonomous Teleoperation**
   Mentors: Dr. Peter Kazanzides and Dr. 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 this to more than 25 institutions around the world. The goal of this project is contribute to the advancement of this research infrastructure. The specific task will take into account the student's background and interests, but is expected be one of the following: (1) 3D user interface software framework, (2) constrained optimization control framework, (3) Simulink Real-Time interface to the robot controller, (4) integration of alternative input devices and/or robots, or (5) development of dynamic models and simulators.

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

7. **Development of a New Remotely Operated Underwater Vehicle: Mechanical Development**
   Mentor: Dr. Louis Whitcomb

   Description: This REU student project is to work with other undergraduate and graduate students to develop a new remotely operated underwater robotic vehicle (ROV) that will be used for research in navigation, dynamics, and control of underwater vehcles. Our goal is to develop a neutrally buoyant tethered vehicle capable of agile six degree-of-freedom motion with six marine thrusters, and to develop new navigation and control system software using the open-source Robot Operating System (ROS).

   Role of REU Student: Mechanical design, fabrication, and testing.
   Background Skills: Experience in CAD (solidworks preferred) and modern manufacturing methods – please submit work examples with application. C++ programming, Linux, and ROS programming experience desired but not required.

8. **Haptic Feedback and Control for Upper-Limb Prosthetic Devices**
   Mentor: Prof. Jeremy D. Brown

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.

Background 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.

9. **Bimanual Haptic Feedback for Robotic Surgery Training**
   Mentor: Prof. Jeremy D. Brown

Description: Robotic minimally invasive surgery (RMIS) has transformed surgical practice over the last decade; teleoperated 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.

Background 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.

10. Multi-functional animal and robot locomotion in complex terrain
Mentor: Prof. Chen Li

Description: Animals are fantastic locomotors and can move through almost any terrain. One main feature that animals have but still lacking for mobile robots is the ability to perform multi-functional locomotion (e.g., run, climb, burrow, self-right). We are systematically studying how animals do so and will use biological insights to guide development of novel robots that begin to be able to achieve multi-functional locomotion. The robots in turn provide us with physical models for systematic experiments to locomotor design and control to discover general principles of locomotion in complex terrains. For example, in recent studies, we found that cockroach has wings that are normally closed to form a rounded body shape that help them traverse cluttered obstacles, but when flipped over they open their wings to self-right; based on these insights, we have developed new robots that can transform between having a rounded shell for obstacle traversal or having wings open for self-righting.

Role of the student: The REU student will be involved in animal and robot locomotion experiments in complex terrains; data analysis; design / fabrication / refinement of novel bio-inspired robots / terrain platforms.

Helpful Skills: No specific animal experiment background is required, but the student must be comfortable handling live insects and reptiles (with mentorship). Arduino microcontroller circuit and programming, CAD design, 3D printing, machining, MATLAB. For more information, visit https://li.me.jhu.edu/ .

11. Robophysical system to study locomotor-terrain physical interaction
Mentor: **Prof. Chen Li**

Description: A main challenge that has prevented robots from moving as well as animals in complex terrain is our lack of understanding of the physical interaction between animals and robots (locomotors) and the surrounding terrain (think about what if we wanted to make an airplane fly but had no idea how to generate lift!). Currently the primary approach of robot locomotion in 3-D terrains is to avoid obstacles (e.g., self-driving cars). However, for small robots dynamically moving through many 3-D terrains such as forest floor or building rubble, it is impossible to always avoid obstacles. Instead, physical interaction between locomotors and environments becomes important. We are developing novel robophysical systems with sensors to systematically study contact and forces relevant for locomotion in such complex 3-D terrains.

Role of the student: The REU student will be involved in development / refinement and systematic testing of our novel robophysical system, and perform data analysis (and potentially simple mechanics modeling).

Helpful skills: Automation, mechatronics, Arduino microcontroller, MATLAB, C++, Robot Operating System, CAD design, 3D printing, machining, IMU / force sensors.

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

12. Photoacoustic Guidance of Robotic Gynecological Surgeries with the da Vinci Robot
Mentors: Dr. Muyinatu A. Lediju Bell, Dr. Peter Kazanzides

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 gynecological surgeries, such as hysterectomies, endometriosis resection, and surgeries to remove uterine fibroids (myomectomies). We are developing a test platform based on a research da Vinci Surgical Robot. The project goal is to perform phantom experiments to quantify the accuracy of the photoacoustic measurements.

Role of REU Student: Literature searches; phantom design and construction; integration of the photoacoustic imaging system with the da Vinci robot; hands-on experiments with the integrated system.

Preferred Background Skills: Ability to perform laboratory experiments and analyze results using MATLAB; Experience with ultrasound and programming experience in C/C++ would be helpful, but not required.

13. Photoacoustic Image Guidance for Neurosurgery
Mentor: Dr. Muyinatu Lediju Bell

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 bone and other tissues during minimally invasive neurosurgery. The project goals are to perform phantom experiments to quantify the performance of the photoacoustic imaging system and to prepare for patient testing to determine clinical utility.

Role of REU Student: Build and test tissue-mimicking phantoms; perform experiments with cadaver head models; prepare a photoacoustic imaging system for clinical studies

Preferred Background Skills: Ability to perform laboratory experiments and analyze results; Programming experience in MATLAB, Python, and C/C++. Experience with ultrasound imaging and lasers would be helpful, but not required.

14. Photoacoustic Imaging of Nerve Blocks
Mentor: Dr. Muyinatu A. Lediju Bell

Description: Photoacoustic imaging has the potential to avoid injury to hidden nerves during surgery and possibly prevent surgery-related paralysis. The technique is implemented by using 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 visualize nerve blocks for avoidance during multiple minimally invasive surgeries. The project goals are to design specialized light delivery systems and to perform experiments with nerve blocks to quantify photoacoustic imaging system capabilities.

Role of REU Student: Phantom design and construction; perform experiments with nerve blocks; data analysis and interpretation; 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 and optics would be helpful, but not required.

15. Photoacoustic Guided Spinal Fusion Surgery

Mentor: Dr. Muyinatu A. Lediju Bell

Description: Photoacoustic imaging has demonstrated capabilities to differentiate various bone properties, which can be particularly useful during surgeries that involve the spinal cord. This imaging technique 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 distinguish cortical from cancellous bone during spinal fusion surgery. The project goals are to perform experiments with spinal bone specimens to quantify the performance of the photoacoustic imaging system.

Role of REU Student: Perform experiments with spinal bone specimens; data analysis and interpretation; 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 and lasers would be helpful, but not required.

16. Software environment and virtual fixtures for medical robotics
Mentors: Prof. Russell Taylor, Dr. Peter Kazanzides

Description: Our laboratory has an active ongoing research program to develop open source software for medical robotics research. This "Surgical Assistant Workstation (SAW)" environment includes modules for real time computer vision; video overlay graphics and visualization; software interfaces for "smart" surgical tools; software interfaces for imaging devices such as ultrasound systems, x-ray imaging devices, and video cameras; and interfaces for talking to multiple medical robots, including the Intuitive Surgical DaVinci robot, our microsurgical Steady Hand robots, the IBM/JHU LARS robot, the JHU/Columbia "Snake" robot, etc. A brief overview for this project may be found at https://www.cisst.org/saw/Main_Page. Students will contribute to this project by developing "use case" software modules and applications. Typical examples might include: using a voice control interface to enhance human-machine cooperation with the DaVinci robot; developing enhanced interfaces between open source surgical navigation software and the DaVinci or other surgical robots; or developing telesurgical demonstration projects with our research robots. However, the specific project will be defined in consultation with the student and our engineering team.

Required Skills: The student should have strong programming skills in C++. Some experience in computer graphics may also be desirable.

17. Instrumentation and steady-hand control for new robot for head-and-neck surgery
Mentors: Prof. Russell Taylor, Dr. Jeremy Richmon (Otolaryngology), Dr. Masaru Ishii (Otolaryngology), Dr. Lee Akst (Otolaryngology), Dr. Matthew Stewart (Otolaryngology)

Description: Our laboratory is developing a new robot for head-and-neck surgery. Although the system may be used for "open" microsurgery, it is specifically designed for clinical applications in which long thin instruments are inserted into narrow cavities. Examples include endoscopic sinus surgery, transphenoidal neurosurgery, laryngeal surgery, otologic surgery, and open microsurgery. Although it can be teleoperated, our expectation is that we will use "steady hand" control, in which 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. 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

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.

18. Software environments and virtual fixtures for medical robots

Mentors: Prof. Russell Taylor, Dr. Peter Kazanzides

Description: Our laboratory has an active ongoing research program to develop open source software for medical robotics research. This "Surgical Assistant Workstation (SAW)" environment includes modules for real time computer vision; video overlay graphics and visualization; software interfaces for "smart" surgical tools; software interfaces for imaging devices such as ultrasound systems, x-ray imaging devices, and video cameras; and interfaces for talking to multiple medical robots, including the Intuitive Surgical DaVinci robot, our microsurgical Steady Hand robots, the IBM/JHU LARS robot, the JHU/Columbia "Snake" robot, etc. A brief overview for this project may be found at https://www.cisst.org/saw/Main_Page. Students will contribute to this project by developing "use case" software modules and applications. Typical examples might include: using a voice control interface to enhance human-machine cooperation with the DaVinci robot; developing enhanced interfaces between open source surgical navigation software and the DaVinci or other surgical robots; or developing telesurgical demonstration projects with our research robots. However, the specific project will be defined in consultation with the student and our engineering team.

Required Skills: The student should have strong programming skills in C++. Some experience in computer graphics or computer vision may also be desirable.

19. Statistical Modeling of 3D Anatomy
Mentor: Prof. Russell Taylor

Description: The goal of this project is creation of 3D statistical models of human anatomic variability from multiple CT and MRI scans. The project will involve processing multiple images from the Johns Hopkins Hospital, co-registering them, and performing statistical analyses. The resulting statistical models will be used in ongoing research on image segmentation and interventional imaging. We anticipate that the results will lead to joint publications involving the REU student as a co-author.

Required skills: Experience in computer vision, medical imaging, and/or statistical methods is highly desirable.

20. Accuracy Compensation for "Steady Hand" Cooperatively Controlled Robots
Mentor: Prof. 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 Skill: 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.

21. Mosquito Dissection Robot
Mentors: Prof. Russell Taylor (PI), Prof. Gregory Chirikjian, Dr. Iulian Iordachita

Description: We have an active collaboration with a company that is developing a malaria vaccine. Part of the vaccine production process involves removing the salivary glands from mosquitoes. In past work, we have developed simple fixtures that have roughly doubled the throughput of the current manual mosquito dissection process while dramatically reducing the "learning curve" time for human technicians to become proficient in the task. Our goal for the next step in the project is development of a fully automated robotic system, based on lessons learned in the previous phase. The REU student will work with others on the project team to assist in development of this system. The specific task will depend on the skills of the student and the phase of development of the project at the time the student is at JHU. Generally, typical tasks will include mechatronic design and implementation of a component subsystem, control of robot components, system integration, and testing. **Note:** We use only non-infected mosquitos at JHU for this research.

Required Skill: At least one of: mechanical design and fabrication; real time device control software; higher level application programming (C++); computer vision.

22. Modeling Human Attention in Oculus Rift
Mentor: Prof. Ralph Etienne-Cummings

Description: What draws your attention when you enter a room? Look at a piece of art? Survey nature? We can model these effects in software. Now we need to provide users with highlighted 3D images of areas of interest that they may have missed. We also need to know where they are looking. Hence, we need a Virtual Reality system that allows use to provide 3D videos to a user and track their eyes and head so we can update the areas of most interest based on gaze. Also, this will allow us to monitor eye movements while visually surveying an area.

Role of REU Student: The REU will work with graduate students to convert our algorithms for real-time operation and overlay onto video that are piped to the Oculus Rift googles.

Preferred Background Skills: Programming, some FPGA, some hardware.

23. Subspace Clustering
Mentor: Prof. Rene Vidal

Motivations: Consider the task of separating different moving objects in a video (e.g., running cars and walking people in a video clip of a street). While human can easily solve this task, a computer would find itself totally clueless, since all that it sees is a big chunk of ordered 0's and 1's. Fortunately for the computers, this problem has a specific property that allows an alternative approach which a computer is more comfortable with. That is, for all the points of the same moving object, the vectors built from their trajectories lie in a common subspace. Thus, this problem boils down to a math problem of separating different subspaces in the ambient space.

Project Goals: Given a set of data points that are drawn from multiple subspaces with unknown membership, we want to simultaneously cluster the data into appropriate subspaces and find low-dimensional subspaces fitting each group of points. This problem is known as subspace clustering, and some of its applications include motion segmentation (mentioned above), image segmentation, face clustering, and hybrid system identification. The Vision Lab has worked extensively on this topic, and it has developed methods of geometric approaches such as Generalized Principle Component Analysis, and spectral clustering approaches such as Sparse Subspace Clustering. The goal of the project is to further improve algorithms for subspace clustering. Possible research directions include:

- To develop scalable algorithms that are able to deal with data that has millions of entries.
- To develop algorithms that can effectively deal with class-imbalanced data and improve clustering accuracy.
- To develop algorithms that are able to deal with missing entries in the data, e.g., incomplete trajectories in the motion segmentation applications.
- To extend current subspace clustering 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.

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

Preferred Background Skills: Strong background in linear algebra and experience in MATLAB/Python coding.

24. Object Recognition
Mentor: Prof. Rene Vidal

Motivations: When a person is shown an image, he/she is able to immediately identify a variety of things like: the various objects present in the image, their locations, their spatial extent, their categories and the underlying 3D scene of which it is an image. The human visual system uses a combination of prior knowledge about the world and the information present in the image to perform this complicated task. We want to replicate this on a computer. This is broadly called object recognition and it involves object detection (is there an object in this video? where is it located?), segmentation (which pixels contain the object?), categorization (what is the object's class?) and pose estimation (what is the 3D location of object in the scene?). We also want to perform all these tasks jointly rather than a pipeline approach as knowledge of one task helps us perform the others better.

Project Goals: The project aims to develop deep learning models and algorithms to perform the tasks of object detection, categorization, image segmentation and pose estimation jointly in a fast and efficient manner. We are designing new architectures that combine these tasks in a holistic manner and learn multi-modal (RGB, Depth, Surface Normal) image representations that are generalizable. We are inventing new representations and loss functions that respect and exploit the underlying structure of 3D pose. We are also developing data augmentation techniques like 3D pose jittering and rendered depth images that are better suited to our tasks.

Internship Goals: As part of the project, the intern will help enhance our current framework for object recognition by improving the model to extend across different data modalities and design algorithms to utilize these models for various vision tasks. The intern will be exposed to current research in the area of Object Recognition and Scene Understanding. He/she will read a lot of literature on a computer vision and machine learning in general with an emphasis on topics like deep learning, convolutional neural networks, and image representations. The intern will implement algorithms in Python/Matlab and test them across various datasets. The intern will present his/her work to other graduate students and professors and will potentially be able to publish his/her research in computer vision conferences and journals. This project will help the intern gain a good understanding of challenges and research opportunities in the area of Object Recognition and Scene Understanding.

Preferred Background Skills: Experience in Python and MATLAB coding and familiarity with image processing, computer vision, or statistical inference.

25. Matrix Factorization
Mentor: Prof. Rene Vidal

Motivations: Many unsupervised machine learning problems can be understood as factorization problems, where one seeks to decompose data into meaningful parts. For example, in principal component analysis we try to represent a data matrix as the product of a low rank basis and a matrix of coefficients. One challenge with factorization problems, however, is that there often exist many equivalent representations which are mere rotations or permutations of one-another. This inherent non-convexity of the underlying optimization problem makes finding good factorizations difficult in general.

Project Goals: In this project, we aim to develop efficient algorithms for finding globally optimal solutions to select matrix factorization problems. Our strategy will be to study the relationship between non-convex matrix factorization, and a convex surrogate problem. We will analyze conditions under which we can solve the convex surrogate and recover a solution to the original factorized problem. This will hopefully lead to state-of-the-art algorithms for solving problems such as low-rank matrix completion (popularized by the Netflix Challenge), and clustering in the presence of missing data.

Internship Goals: As part of the project, the intern will work alongside PhD students to implement and evaluate algorithms for solving several non-convex matrix factorization problems. The intern will learn necessary background knowledge in machine learning and optimization to contribute to this research. The intern will gain experience implementing novel algorithms in MATLAB/Python, and evaluating them against synthetic and real-world datasets. The intern will present his/her work to other graduate students and professors and will potentially be able to publish his/her research in machine learning conferences and journals. As part of the group, the intern will experience first-hand a rigorous and rewarding research environment.

Preferred Background Skills: Strong background in linear algebra, optimization, and experience in MATLAB/Python coding.

26. Deep Learning
Mentor: Prof. Rene Vidal

Motivations: 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. Deep learning methods exhibit strange behaviors which defy explanation. Why does generalization performance only seem to improve as network complexity increases? How is stochastic gradient descent able to converge to networks with zero loss, despite the dramatic 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: The deep learning optimization problem is highly non-convex: there exist many equivalent, locally-optimal, weight configurations, separated in the optimization landscape by ridges of poor configurations. This makes the process of finding good network weights a challenging combinatorial problem, in principle. Confusingly however, deep network training works remarkably well in practice.

Recent theoretical work shows that if a deep network is allowed to vary in size, and the network activation is enforced to be positively homogeneous--a condition which the popular rectified linear activation satisfies--then the non-convex learning problem admits a tight convex relaxation. This suggests that for this kind of deep network, the optimization landscape, although non-convex, has nice structure enabling efficient solution. In this project, we will investigate this hypothesis experimentally, by studying the deep learning optimization landscape for different network architectures, activation functions, and forms of regularization.

Internship Goals: As part of the project, the intern will work alongside PhD students to develop experimental methods to probe the extremely high-dimensional deep learning optimization landscape. The intern will learn necessary background knowledge in machine learning and optimization to contribute to this research. The intern will gain experience implementing small and medium-scale deep networks using popular deep learning frameworks, and evaluating their behavior. The intern will present his/her work to other graduate students and professors and will potentially be able to publish his/her research in machine learning conferences and journals. As part of the group, the intern will experience first-hand a rigorous and rewarding research environment.

Preferred Background Skills: Strong background in linear algebra, optimization, and experience in MATLAB/Python coding.

27. Activity Recognition
Mentor: Prof. Rene Vidal

Motivations: 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. We are especially interested in designing activity recognition algorithms to be integrated in rehabilitation of young children with mobility disorders. As a part of the project, we would like to design algorithms to analyze data collected from a network of cameras during physical therapy sessions and recognize the actions performed by the baby at each timestep.

Internship Goals: As part of the project, the intern 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 intern will implement code for these algorithms as well as test them on several benchmark datasets. The intern will read research papers on activity recognition and time-series modeling, and will learn new techniques to solve the above problem. Moreover, the intern will implement novel algorithms in Python (MATLAB/C++) and become familiar with several computer vision and machine learning concepts. The intern will present his/her work to other graduate students and professors and will potentially be able to publish his/her research in computer vision conferences and journals. As part of the group, the intern will experience first-hand a rigorous and rewarding research environment.

Preferred Background Skills: Experience in programming (Python/MATLAB/C++) and familiarity with computer vision and basic machine learning techniques (such as Support Vector Machines, Hidden Markov Models and Neural Networks).

28. Accelerated Non-Convex Optimization
Mentor: Prof. Rene Vidal

Motivations: Optimization is at the core of almost every problem in machine learning and statistics. Modern problems require the minimization of a function of several variables in high dimensions, depending on a very large number of data points. Moreover, this function may be nonconvex, which means that the point of global minimum is hard to find, since there may be several local minimum and saddle points. Nonconvex optimization is an intense area of modern research in mathematics and computer science, and only recently some progress has been made in partially understanding how commonly used algorithms perform on a class of nonconvex problems. On the other hand, in convex optimization, it is possible to accelerate a class of algorithms with an order of magnitude gain in speed. Also, partial progress towards an understanding of the acceleration mechanism has only been made very recently. Our group is working on this cutting-edge frontier between mathematics and computer science, combining both approaches with the goal of studying accelerated algorithms for nonconvex problems, from mathematical and applied perspectives.

Project Goals: We want to understand known accelerated algorithms in nonconvex settings, and also to propose new accelerated algorithms. These methods will be applied to subspace clustering, matrix factorization, and matrix completion, which are important problems in machine learning. We aim at making solution methods to these problems faster and more scalable.

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

Preferred Background Skills: A strong background in mathematics and working experience in Python or MATLAB.

29. Flexible Transparent Electrode Development for Infrared Optoelectronics
Mentor: Dr. Susanna Thon

Project Description: Infrared photon sensing and detection technology is of interest for a variety of applications in medicine, communications, and computing. Solution-process materials, such as colloidal quantum dots, have the potential to act as low-noise photodetectors for short-wave infrared (SWIR) radiation that can operate at room temperature, but integrating them with traditional read-out electronics is a challenge due to the need for flexible, transparent contacts and interlayers. The aim of this project is to develop new all solution-processed materials, such as silver nanowires and colloidal metal oxides, as flexible transparent electrodes for optoelectronic devices including photodetectors, solar cells, and LEDs. The project will include computational design, chemical synthesis, device fabrication, and optical/electronic testing components.

Role of the Undergraduate Student: The undergraduate researcher will be in charge of doing optical measurements (broadband absorption/reflection/transmission spectroscopy) and simulations using commercial and existing software to characterize and optimize new transparent electrode materials. Additionally, the undergraduate researcher will fabricate thin-film transparent electrodes on flexible substrates, and assist graduate students with colloidal materials synthesis and device testing.

Preferred Background Skills: Familiarity with Matlab is preferred. Some experience or comfort level with wet chemistry techniques is desirable but not required. All lab skills will be taught as-needed.

30. Using Machine Learning for Learning Information from Clinical Notes
Mentor: Dr. Suchi Saria

Project Description: Clinical notes contain rich unstructured information about a patient's condition during their hospital stay. Critical information like patient history, qualitative observations, and diagnoses may only be recorded in the clinical notes. However, the unstructured and highly technical nature of the notes makes this information hard to extract automatically. Moreover, most existing natural language processing frameworks are not adept at handling medical text. In this project we will use machine learning techniques to develop a pipeline for automatically extracting information from clinical notes that could later be used in building disease modeling systems. The resulting information are critical in making automated surveillance algorithms

Good background in programming (at least one class in object oriented programming and/or familiarity with C++, Java or Python) is recommended. While useful, a medical background is not required. A class in natural language processing or experience in implementing machine learning algorithms (even as a hobby project) will be seen as a plus but is not required. Most of all, we want to work with someone who is a self-starter and is eager to learn and deploy machine learning algorithms.