

MIT Beaver Works Summer Institute

MIT Beaver Works Summer Institute 2019



Autonomous
RACECAR
Grand Prix



Autonomous
Air Vehicle
Racing



Autonomous
Cognitive
Assistant



Data Science
for Health &
Medicine



Build a
CubeSat



UAS-SAR



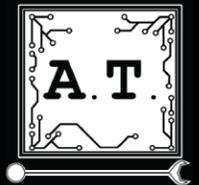
Embedded
Security and
Hardware Hacking



Hack A
3D Printer



Remote
Sensing



Assistive
Technology



BEAVER WORKS
Lincoln Laboratory | School of Engineering



LINCOLN LABORATORY
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OFFICE OF
DIGITAL LEARNING



Massachusetts Institute of Technology



MIT Lincoln Laboratory



MIT Lincoln Laboratory / School of Engineering Beaver Works

MIT Beaver Works Summer Institute

Dear Friends, Family, and Engineering Enthusiasts,

The brochure below includes all information on the 2019 Beaver Works Summer Institute!

The MIT Beaver Works Summer Institute is a rigorous, world-class STEM program for talented rising high school seniors. The 2018 program featured eight project-based, workshop-style courses: Autonomous RACECAR Grand Prix, Autonomous Air Vehicle Racing, Autonomous Cognitive Assistant, Data Science for Health and Medicine, Build a CubeSat, UAS-SAR, Embedded Security and Hardware Hacking, and Hack a 3D Printer.

This year's MIT Beaver Works Summer Institute was a complete success thanks to the enthusiasm of our students, the dedication of our instructors, and the hard work of our team members. We partnered with 106 high schools to recruit the future engineers who participated in our program. We had the pleasure of working with 198 students, 131 of whom joined our program from outside Massachusetts.

In the coming years, we will integrate new programs into this initiative, increasing participation substantially. We will support high school STEM teachers who use our teaching materials to help better prepare their students for college and beyond. We will also help other universities and high schools create similar programs, working to build a network of institutes to collectively improve engineering education worldwide.

Thank you for the continued support of our program.

The MIT Beaver Works Summer Institute Staff

What Is Beaver Works Summer Institute?

The MIT Beaver Works Summer Institute (BWSI) is a rigorous, world-class STEM program for talented students who will be entering their senior year in high school. The four-week program teaches STEM skills through project-based, workshop-style courses. BWSI began in 2016 with a single course offered to 46 students, a mix of local daytime students and out-of-state residential students. In this course, RACECAR (Rapid Autonomous Complex Environment Competing Ackermann steering), students programmed small robotic cars to autonomously navigate a racetrack.

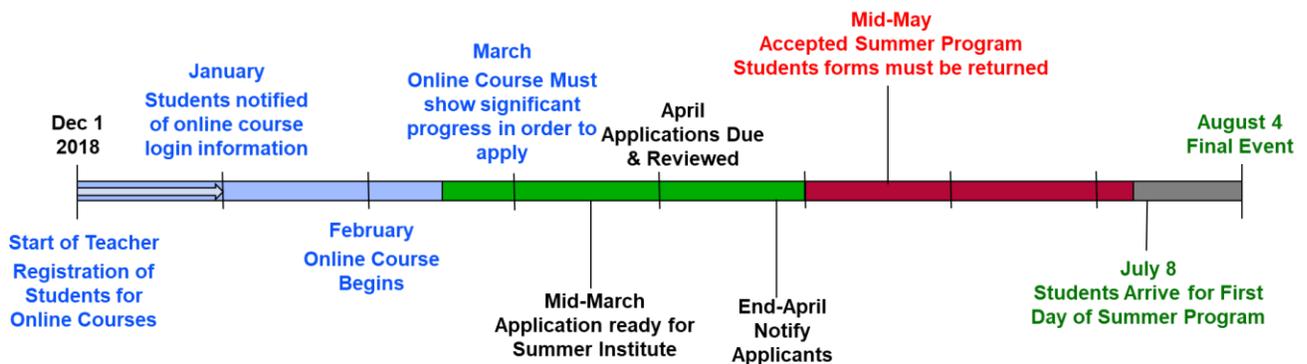
The positive student reaction to our hands-on learning style led to the expansion of the program to include two new courses in 2017. To make sure students had the STEM background to participate fully in the three courses, the BWSI instructors developed online tutorials that students had to complete as a prerequisite for applying for the summer program. The new courses were Autonomous Air Vehicle Racing and Autonomous Cognitive Assistant. In 2017, 98 students from 49 high schools nationwide enjoyed BWSI.

In 2018, we grew again. This year, we added five courses to our three earlier ones; each new course also has a requisite online tutorial. All eight courses are described in more detail further on in this pamphlet. The 2018 class of BWSI boasted 198 young people from 106 high schools from across the country and Puerto Rico. Both last year and this, we have had teams from Massachusetts and outside the United States participate in our RACECAR Grand Prix after they completed the course curriculum on their own.

We believe we have reached an optimal enrollment number. Expansion in the coming years will focus on developing new courses and working with collaborators to scale up the program nationally and internationally. We will continue to advise high school STEM teachers who want to incorporate the BWSI concepts and materials into their classrooms. Our vision is a broad network of BWSI-like programs that will help improve engineering education, and toward that goal, we will share our work and ideas with universities and high schools worldwide.

Contact us at bws-admin@mit.edu for information on how to adopt this program into your school curriculum.

BWSI 2019 Timeline of Program requirements.



What is Beaver Works?

Beaver Works is a joint venture between MIT Lincoln Laboratory and the MIT School of Engineering that is envisioned as an incubator for research and innovation. Beaver Works facilitates project-based learning, a hallmark of an MIT education, and leverages the expertise and enthusiasm of MIT faculty, students, researchers, and Lincoln Laboratory staff to broaden partnerships across both institutions.

The Beaver Works center located in Cambridge, Massachusetts, provides these facilities: areas for collaborative brainstorming; workshops and tools for fabricating prototype systems; and space for classroom-style instruction. Beaver Works allows students to address real-world problems and issues, engages students in hands-on learning, and demonstrates an effective strategy for teaching complex engineering concepts.

Beaver Works supports MIT student involvement in a range of research and educational pursuits, including two-semester, course-based capstone projects; joint and individual research initiatives; and Undergraduate Research Opportunities Program internships. Students involved in these projects develop innovative solutions to real-world problems and gain an exceptional experience in hands-on learning from world-class researchers.

In addition to the Summer Institute, Beaver Works is also extending project-based learning opportunities to local K–12 schoolchildren. Among these offerings have been a robotics workshop for an all-girl FIRST (For Inspiration and Recognition of Science and Technology) LEGO League team, a hands-on camera-building activity for high-school girls, and a one-day workshop on radars for students in middle school.

MIT Beaver Works Summer Institute

2019 Summer Program: Course Overview

The MIT Beaver Works Summer Institute will consist of the following courses. For more information on each course, see the following pages in this brochure.

Autonomous RACECAR Grand Prix

Beaver Works Summer Institute will offer teams of students, each with its own MIT-designed RACECAR robot, the opportunity to explore the broad spectrum of research in autonomy; learn to collaborate, and demonstrate fast, autonomous navigation in a Mini Grand Prix to ***Move... Explore... Learn...Race!***

Autonomous Air Vehicle Racing

Beaver Works Summer Institute will offer students the opportunity to explore some new areas of research and to design their own autonomous capabilities for UAVs (unmanned aerial vehicles). The students will work in teams to develop algorithms for deployment to an advanced quadrotor, the Intel Aero Ready-To-Fly Drone. They will use the Robot Operating System (ROS), popular open-source libraries, and custom algorithms to program the quadrotors to compete in a racing event.

Autonomous Cognitive Assistance

Beaver Works Summer Institute will offer students an opportunity to learn about the cutting-edge in machine learning. Cog*Works consists of project-based modules for developing machine learning apps that leverage audio, visual, and linguistic data. Students will work with experts in these fields to learn foundational mathematical, programming, and data analysis skills, which will enable them to create their own algorithms and neural networks from scratch. Ultimately, they will design their own cognitive assistants.

Build a CubeSat

Beaver Works Summer Institute will offer students the opportunity to select the mission, test components and design a CubeSat. Using a 1U CubeSat (10 cm x 10 cm x 10 cm), the four-week course will guide the class through the design trades, assembly, and testing of a CubeSat with an imaging payload. The design will be sent to a NASA competition selecting payloads for future flight.

Hacking a 3D Printer

Beaver Works Summer Institute will introduce students to the fundamentals of 3D printing and teach techniques for tuning hardware and software to optimize performance. Students will modify these components to do something completely new. Along the way, students will learn how to tackle difficult problems.

Unmanned Air System–Synthetic Aperture Radar

Beaver Works Summer Institute will introduce students to Synthetic Aperture Radar (SAR) imaging as they build and fly a radar on a small Unmanned Aerial System (UAS) and use it to image scenes around campus. Students will work in small teams alongside their instructors to gain hands-on experience building, integrating, and processing data from a radar to generate SAR images. Teams will compete to create the UAS-SAR capable of producing the clearest images possible.

Medlytics (Data Science for Health and Medicine)

Beaver Works Summer Institute will give students a chance to explore the exciting intersection of data science and medicine. Students will build a solid foundation in the fundamentals of probability and statistics, and learn the basics of coding and machine learning techniques through a series of online teaching modules. During the summer, students will work in groups alongside Cambridge-area clinicians and data scientists to gain hands-on experience applying advanced machine learning and data mining to solve real-world medical challenges.

Embedded Security and Hardware Hacking – MITRE Project

Beaver Works Summer Institute will cover several cybersecurity topics with a focus on threats that are especially concerning for embedded systems. These topics include embedded software security, JTAG and UART probing, side-channel analysis, and fault-injection. This background will help prepare students for the summer course, during which they will design and perform security assessments of multiple implementations of an embedded system. They will learn the basics of embedded security and hardware hacking by designing a secure system and performing security assessments of classmates' designs to see who can find and fix the most security flaws.

Remote Sensing For Crisis Response

Beaver Works Summer Institute will offer students the opportunity to explore the exciting intersection of data science and crisis response. During the course, the students will learn to understand the basics of Python, Git, machine learning, and image processing through a series of online teaching modules. Students will explore real world datasets ranging from drone imagery of regions to disaster imagery collected by the human volunteers of the Civil Air Patrol. Students will develop experience in an area of data science that is poised to play a critical role in understanding our world.

Assistive Technology

Beaver Works Summer Institute will help students develop product design, rapid prototyping, and product testing skills in the context of building a technology solution for people living with disabilities. We will tackle real problems faced by people in the Greater Boston Area, and learn to work with the end users, stepping through the engineering design process together to come up with personalized, creative solutions.

MIT Beaver Works Summer Institute

2019 Summer Program: Autonomous RACECAR Grand Prix Challenge



Autonomous RACECAR Grand Prix

Program Overview

Driverless vehicle technology has been growing at an exponential pace since the DARPA Grand and Urban Challenges pushed the state of the art to demonstrate what was already possible. Commercial interest and aggressive development are being driven by Google, Toyota, Tesla, Continental, Uber, Apple, NVidia, and many other companies. There is no single technology or “killer app” available to solve the myriad perception, understanding, localization, planning, and control problems required to achieve robust navigation in highly variable, extremely complex and dynamically changing environments. This summer, Beaver Works Summer Institute will offer nine teams of five students, each with its own MIT-designed RACECAR (Rapid Autonomous Complex Environment Competing Ackermann steeRing) robot, the opportunity to explore the broad spectrum of research in these areas, and learn to collaborate, and demonstrate fast, autonomous navigation in a Mini Grand Prix to ***Move... Explore... Learn...Race!***

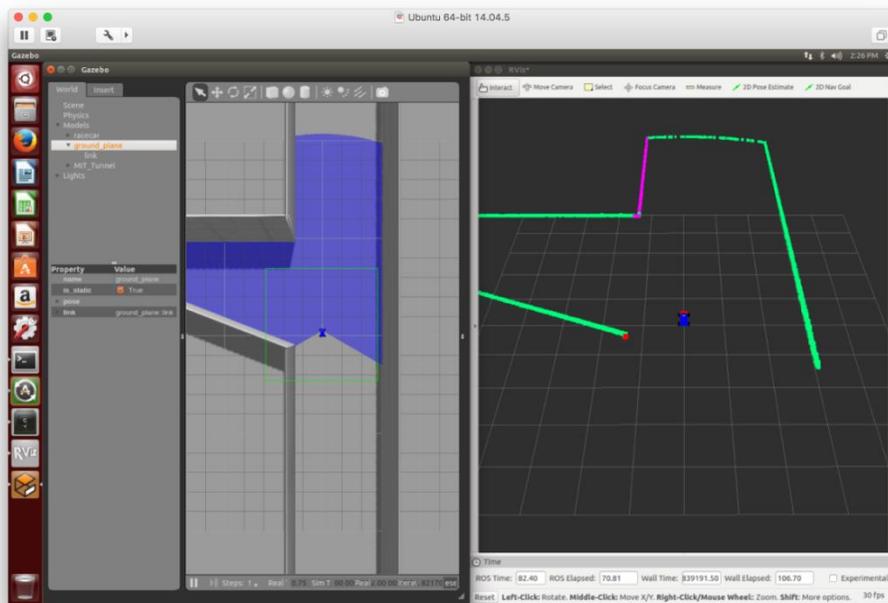
This program consists of two components: an online course from January to May open to all interested students and a four-week summer program at MIT from July 8 to August 4 for a select group of students. The online component gives students a background in the basic concepts and tools that will be used during the summer program. The Robot Operating System (ROS) provides a rich set of tools that may be programmed at a high level with the Python programming language. A model of the RACECAR suitable for use in the Gazebo simulator allows online students to develop skills and demonstrate the basic concepts without requiring a physical RACECAR.

Completing the online curriculum will prepare students to cover the topics of Control Systems, Computer Vision, Localization, Planning, and Navigation at a more advanced level in the summer. The RACECAR is capable of achieving speeds of 40 mph, utilizing

data from real sensors processed with an onboard NVidia TX-1 embedded computer. Such a demonstration of safe, robust autonomous navigation is a significant challenge. A team of experienced MIT researchers will provide the lectures each day, covering material that reviews autonomy fundamentals and expanding on advanced topic areas in the lecturers' expertise. A series of graduated exercises, hands-on labs, and weekly challenge demonstrations will be provided to lead students through the process of developing their solutions to the fundamental problems. In addition, guest lecturers from among leading researchers in the computer science, engineering, and autonomous vehicle academic and corporate communities will provide students with insight into emerging trends in these fields.

Online Course

The online component for the Autonomous RACECAR course contains important introductory material to provide students with the background required to successfully complete the four-week summer course. A virtual machine image is provided for students to download and use on their own computers, with necessary tools preinstalled, so that they can work through both the introductory and more advanced topics and explore problems specific to autonomous vehicles.



RACECAR model navigating simulated Gazebo world with synthetic sensor data

Introduction and Prerequisites

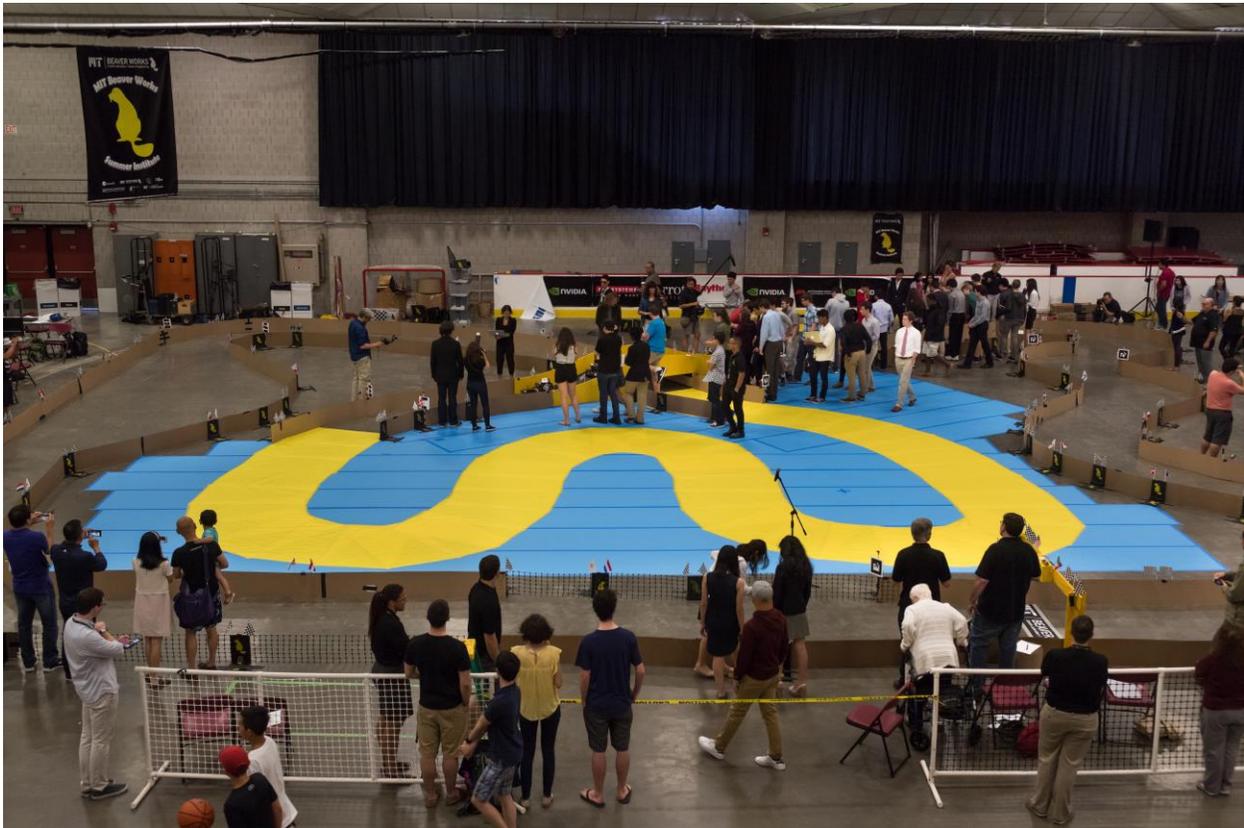
- Installing and using the virtual machine
- Reviewing the overview of the Ubuntu/Linux environment
- Learning the basics of Python programming
- Completing an introduction to the Robot Operating System

Autonomous Vehicles

- Using the RACECAR model in the Gazebo simulation environment
- Studying basic control systems
- Studying fundamentals of computer vision using the OpenCV library
- Acquiring elementary navigation and planning concepts

Summer Course

The four-week summer program is based on the BWSI 2017 course, with additional online material that prepares students to begin the summer course at a more advanced level. The curriculum is being expanded this year to emphasize the use of computer vision and machine learning techniques in autonomous navigation.



Each day in the course will consist of a mix of lectures and hands-on projects to reinforce and apply the material. The detailed topics for each week are listed below:

Week 1: Move...

- RACECAR system operation and sensors
- Robot Operating System principles
- Basic motion control and simple obstacle avoidance

Week 2: Explore...

- Computer vision techniques
- Vision-based blob, target, and object detection
- Visual navigation

Week 3: Learn...

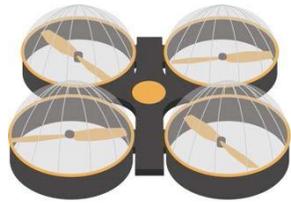
- Mapping unknown environments
- Planning paths to achieve goals
- Navigating in dynamic environments

Week 4: Race!

The final race will be held in the MIT Johnson Ice Rink on August 4, 2019. A wide variety of challenges will require that a range of behaviors be implemented to allow the racecar to make high-level decisions based on visual perception in order to complete a circuit of the track.

MIT Beaver Works Summer Institute

2019 Summer Program: Autonomous Air Vehicle Racing

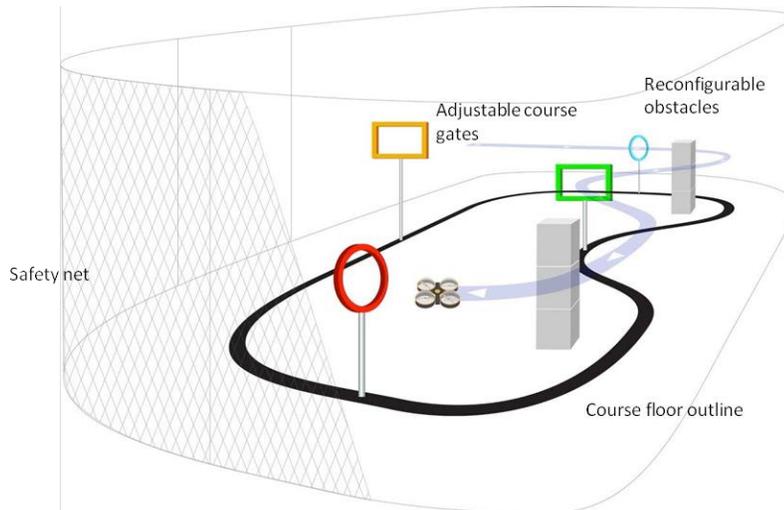


Autonomous Air Vehicle Racing

Program Overview

Rapidly expanding unmanned aerial vehicle (UAV) technology has enabled a number of new application areas. The growth in UAV development is evident in the popularity of First Person View (FPV) drone racing, and interest from companies, like Amazon and others, to develop fully autonomous aerial delivery vehicles. As UAV technologies mature, they open new and exciting areas for potential research. This summer, Beaver Works will offer students the opportunity to explore some of these new areas of research, and to design their own autonomous capabilities for UAVs. The students will work in teams to develop algorithms for deployment on a commercial quadrotor, the Intel Aero Ready-to-Fly Drone. They will use the Robot Operating System (ROS), various open-source libraries, and custom algorithms to program the quadrotors. The summer course will culminate in a competition at which the students will apply the knowledge gained from the four-week program's projects and lectures to a series of racing challenges.

This program consists of two components: an online course from January to May open to all interested students and a four-week summer program at MIT from July 8 to August 4 for a small group of students. The online component gives students a background in the course material, and provides a solid mathematical foundation that will be critical when completing the more advanced topics of the summer course. Students will demonstrate basic implementations of control and autonomy after each unit of instruction. These lessons will build upon previous instruction to enable students to develop algorithms so that a quadrotor can autonomously navigate a UAV racecourse designed for the summer program.



Conceptual UAV Race Course

Online Course

The online component for the Autonomous Air Vehicle Racing course will contain important introductory material that will provide students with the background required to successfully complete the four-week summer course. In addition to the introductory material, the online course will include more advanced, quadrotor-specific material so that students can begin to explore problems specific to autonomous aerial vehicles.

Introduction and Prerequisites

- Introduction to quadrotors
- Linear algebra
- Basics of matrix mathematics
- Introduction to probability and statistics
- Computer programming fundamentals

Autonomous Aerial Vehicles

- Flight geometry
- Actuators and control
- State estimation
- Sensing
- Basic control theory
- Computer vision
- Visual motion estimation

Summer Course

The four-week summer program will be structured to provide the students with projects and hands-on exercises. The program will apply and expand upon the online course material, leading to multiple competitive team challenges in autonomous UAV control. Each day the course will consist of a mix of lectures and hands-on projects to reinforce and apply the material. A team of experienced MIT researchers will provide the lectures, covering material that reviews UAV and autonomy fundamentals and expanding on advanced topic areas in the lecturer's expertise. Hands-on projects will enable the students to apply each lecture, working toward a capability for autonomous UAV racing by using the provided drone and associated experimentation equipment. In addition, the course is lining up guest lecturers from among

leading researchers in the computer science, autonomy, and air vehicle academic and corporate communities to provide the students with emerging trends in these fields. Upon completion of the four-week course, the students will have developed an understanding of autonomous systems development; including controls, flight dynamics, navigation, and computer vision.

The course extends over four weeks of instruction and hands-on practice and one week of team challenges, culminating in the final UAV racing challenge. The detailed topics for each week are listed below:

Week 1: Flight

- Quadrotor design
- Quadrotor dynamics
- Quadrotor components

Week 2: Vision

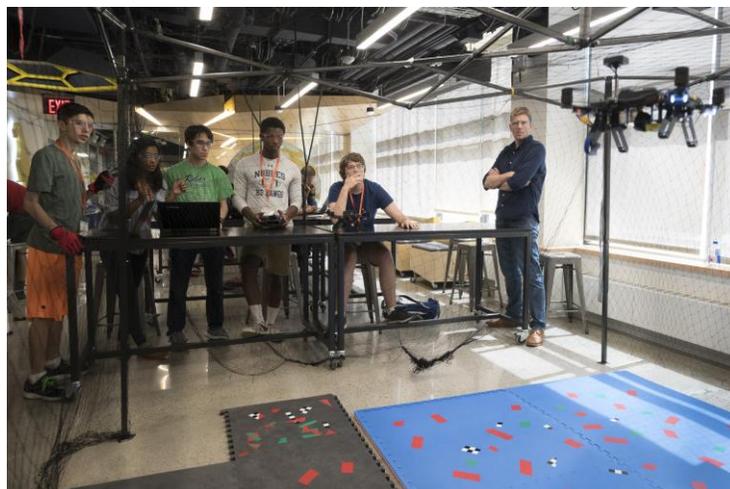
- Image formation
- Edge detection
- Image filtering
- Object detection

Week 3: Control

- Control systems
- State estimation
- Navigation and planning

Week 4: Racing Challenges

The final week of the course will focus on hands-on team projects in autonomous UAVs and racing challenges, leveraging the lessons learned from the first three weeks of the course.



MIT Beaver Works Summer Institute

2019 Summer Program: Autonomous Cognitive Assistant



Program Overview

Artificial intelligence research has achieved a dramatic resurgence in recent years, as innovation of novel deep learning and other machine learning tools has enabled machine performance surpassing humans in specific cognitive tasks. New records in “machine thinking” seem to be set almost daily. This summer, the BWSI is offering students a chance to learn and use the state-of-the-art machine learning tools in a program called Cog*Works: Build your own Cognitive Assistant. The program will guide students in learning and applying the foundational technologies of artificial intelligence for building cognitive assistants. Students who have successfully completed the online course will be considered for participation in the summer program in which teams of students will leverage professional cognition services (e.g., Amazon Alexa/Echo) and open-source tools in conjunction with their own machine learning tools to develop cognitive systems. The program will be divided into modules during which students will implement and explore algorithms in core areas of natural language processing and machine cognition. These capabilities will be composed to create end-to-end cognitive assistants that will compete against each other at the end of the program.

This program consists of two components: (1) online course from January to May 2019, open to all interested and committed students, and (2) a four-week summer program at MIT for a small group of students, July 8–August 4. During the course, the students will be trained to understand the basics of Python, Git, natural language processing, and machine learning through a series of online teaching modules. Students will build services that are both functional and fun. By participating in the online and/or onsite portion of the program, students will develop experience in an area of computer science that is poised to play a critical role in shaping future technologies and applications across many industries.

Online Course

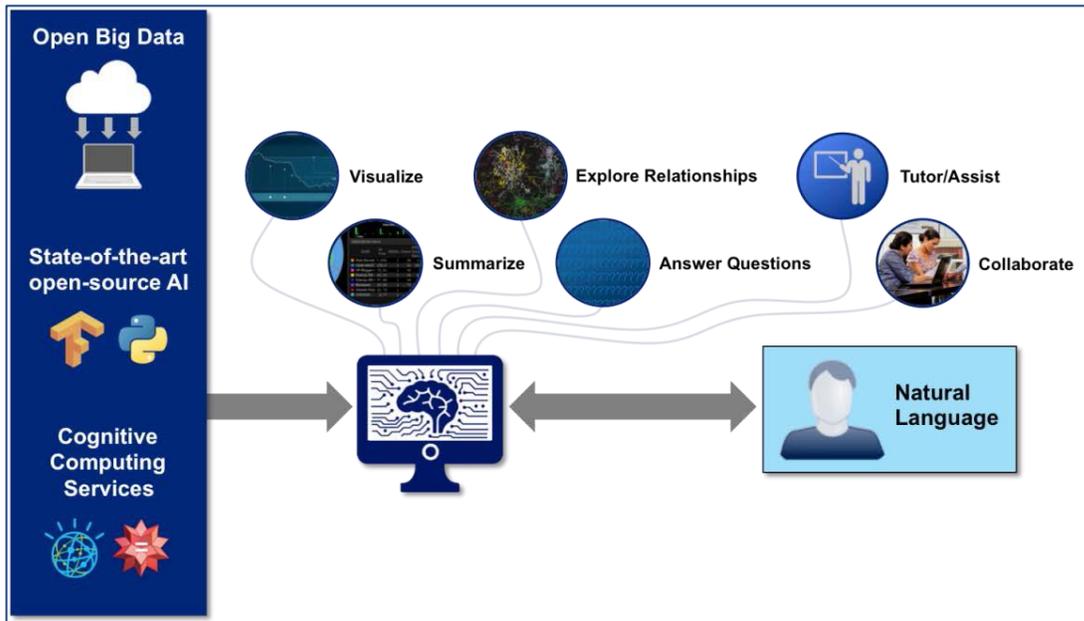
The online component for the Cog*Works course will contain important introductory material that will provide students with the background required to successfully complete the four-week summer course. In addition to the introductory material, the online course will include more advanced machine learning–specific material that will enable students to begin exploring problems specific to cognitive assistants.

Introduction and Prerequisites

- Introduction to Python
- Git & Github management tools
- Perspectives on machine learning

Autonomous Cognitive Assistants

- Advanced NumPy
- Simple image classification with Python
- Introduction to neural networks
- Introduction to Web Services
- Introduction to Microsoft Cortana ©, and Amazon Alexa © services



Summer Course

The four-week summer component of the BWSI Cog*Works course aims to guide students through the process of creating their own cognitive assistants. Daily lectures from course instructors and guest speakers will solidify and expand upon the content from the online portion of the course. Students will collaborate in small groups to complete milestone projects that are based on their lecture materials. These projects will allow for creative customization and enhancements from the students, and weekly awards will be given to the group(s) with the most "interesting" projects. Ultimately, these projects will serve as the components that compose an end-to-end cognitive assistant.

The following is a rough outline for the summer course:

Week 1: Audio

- Python/NumPy/Github review
- Audio recording, sampling, and encoding
- Discrete Fourier transforms and their applications
- Pattern recognition in audio data
- Audio capstone project

Week 2: Visual

- Review of machine learning concepts
- Coding your own autograd library
- Training dense neural networks
- CNNs and RNNs
- Visual capstone project

Week 3: Language

- Representing written language numerically
- Document comparison and summarization
- Training a language model
- Training word embedding
- Information retrieval
- NLP capstone project

Week 4: Challenges

- Customize your own neural network

MIT Beaver Works Summer Institute

2019 Summer Program:

Medlytics



Program Overview

Data mining and machine learning have become ubiquitous in the age of “big data,” and for good reason: advanced learning algorithms take advantage of ever-growing compute capacity and vast amounts of data to solve complex problems that can often meet or exceed human ability. These techniques are being embraced in nearly every sector including financial trading, cybersecurity, entertainment, advertising, autonomous vehicles, and of course health and medicine. The increasing adoption of electronic health records, mobile health apps, and wearable technologies continues to generate troves of rich, real-time, high-resolution data. This data is now being used to train algorithms to help physicians build prognostic models, conduct medical image analysis, and improve diagnostic accuracy.

In 2019, the new BWSI Medlytics program will offer students the opportunity to explore the exciting intersection of data science and medicine. The program consists of two components: (1) online course from January to May 2019, open to all interested and committed students; and (2) a four-week summer program at MIT campus in Cambridge, MA for a group of 20-25 students from July 8—August 4, 2019. The online course will help students build a solid foundation in the fundamentals of probability and statistics, and provide an introduction to coding and machine learning techniques through a series of online teaching modules. During the summer, students will work in groups alongside Cambridge-area clinicians and data scientists to gain hands-on experience applying advanced machine learning and data mining to solve real-world medical challenges.

Online Course

The online component for the BWSI Medlytics course contains important introductory material to provide students with the background required to successfully complete the four-week summer course. In addition to the introductory material, the online course will expose students to real-world data and machine learning techniques, and introduce some of the

challenges and opportunities of combining the two.

Introduction

- Perspectives on the challenges of working with medical data
- Probability & statistics
- Introduction to coding: Python, Git, Jupyter

Data Science for Health and Medicine

- Defining a patient cohort
- Correlation and regression; noise vs. outliers
- Beginner machine learning: supervised and unsupervised algorithms
- Introduction to time series data analysis



Summer Course

The four-week summer component of Medlytics will take a deep-dive into the application of data analytics to structured data, physiological signals, and medical imagery. Prepared course material, case studies, and small-group projects will expose students to some of the challenges inherent to working with medical data and introduce them to state-of-the-art machine learning tools. Boston-area clinicians, academics, and industry leaders will visit the class to give daily guest seminars, providing valuable real-world knowledge and insights.

Students will compete in weekly challenges and participate in a final capstone project from concept proposal to live demonstration.

The following is a rough outline for the summer course:

Week 1: Introduction to Diagnostic Research and Machine Learning

- Research questions, hypotheses and objectives
- Structured data processing and plotting in Python
- Classification evaluation and metrics
- Supervised machine learning
- Clinical Data Challenge 1: Diagnosing Hypothyroidism

Week 2: Signals Processing and Deep Learning

- Introduction to signals processing
- Fourier transforms
- Machine learning for time-series data
- Artificial neural networks
- Clinical Data Challenge 2: Classifying Sleep Stages

Week 3: Image Processing and Advanced Data Analytics

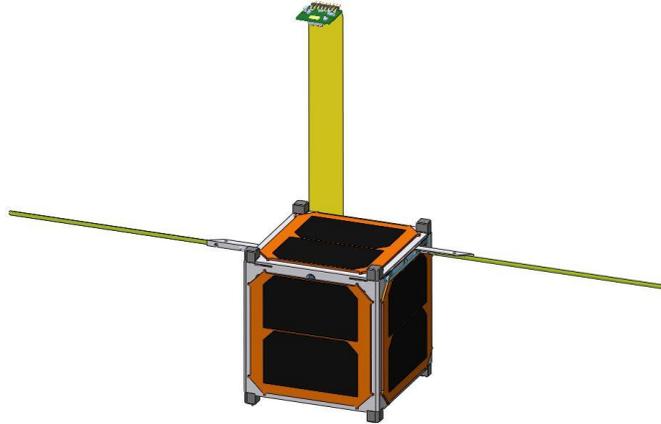
- Computer vision applications in medicine
- Texture classification using convolutional neural networks
- Transfer learning
- Clinical Data Challenge 3: Analyzing Mammograms

Week 4: Capstone Project

In the final week of the course, students will work in teams to propose, design, and demonstrate a health application prototype, leveraging the lessons learned from weeks 1-3.

MIT Beaver Works Summer Institute

2019 Summer Program: Build a CubeSat ¹



Program Overview

In 2019, this BWSI course is dedicated to space but grounded in science. The course will guide students through selecting a mission for earth observation, and design a small satellite for possible inclusion in upcoming NASA launch. Based around a 1U CubeSat (10 cm x 10 cm x 10 cm), the four-week course will guide the class through the design trades, assembly, and testing of a CubeSat with an imaging payload. The program will consist of two components. The first is a series of online courses teaching the basics of satellite development coupled with computer-driven exercises that will allow the class to perform key design trades for the mission involving communication, power generation and usage, size, mass, and performance. The four-week summer program will review the key points from the online course and add in lessons on how to handle and test hardware before heading into the lab to assemble and test a working satellite. During the summer course, students will work with Lincoln Laboratory staff and MIT graduate students to gain hands-on experience in building a space system.

The progression of miniature electronics coupled with the availability of launch rideshares provides access to space for a wide range of organizations that weren't able to dream of such capability 20 years ago. The advent of the CubeSat standard by Bob Twiggs and Jordi Puig-Suari in 1999 opened up real, achievable access to space for student projects that allows for hands-on development experience for the next generation of scientists and engineers.

Online Course

The online component for the BWSI CubeSat course contains important introductory material to provide students with the background required to successfully complete the four-week

¹ Ozmen Foundation Fund at the Community Foundation of Western Nevada

Introduction and Prerequisites

- Why we go to space?
- Basics of rockets and orbital dynamics (using Systems Toolkit)
- Spacecraft subsystems

Satellite Design Work

- Spacecraft systems design trades
- Power systems
- Communications systems
- Payloads and camera performance

Summer Course

The four-week summer component of BWSI CubeSat will focus in the lab on building and testing spacecraft hardware. Daily lectures will review the basics with the students, and guest lectures on key spacecraft systems will be given. In the lab, students will split into subsystem teams to get hands-on exposure to hardware testing, assembly, and environmental screening. Students will be mentored by Lincoln Laboratory staff and MIT faculty and graduate students.

The following is a rough outline for the summer course:

Week 1: “Space, The Final Frontier” Hardware Basics and Systems Engineering

- Space systems 101
- Basic hardware safety and handling
- Software fundamentals

Week 2: Spacecraft Subsystems

- Testing and assembly of all subsystems
- Payloads and camera performance
- Communication and power
- Software, the glue that holds it all together

Week 3: “Houston We Have A Problem” Making It All Work Together

- Subsystem integration
- System and software testing
- Debugging and testing a flight system

Week 4: “Shake and Bake” Environmental Test and Simulation

- Final functional testing
- Launch simulation via servo-hydraulic test system
- Vacuum and thermal performance

Must be a U.S. citizen to participate in this course.

MIT Beaver Works Summer Institute

2019 Summer Program:

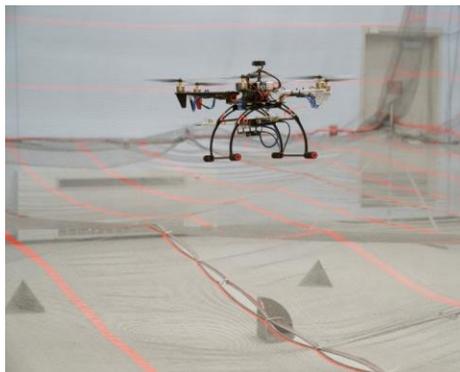
Unmanned Air System - Synthetic Aperture Radar



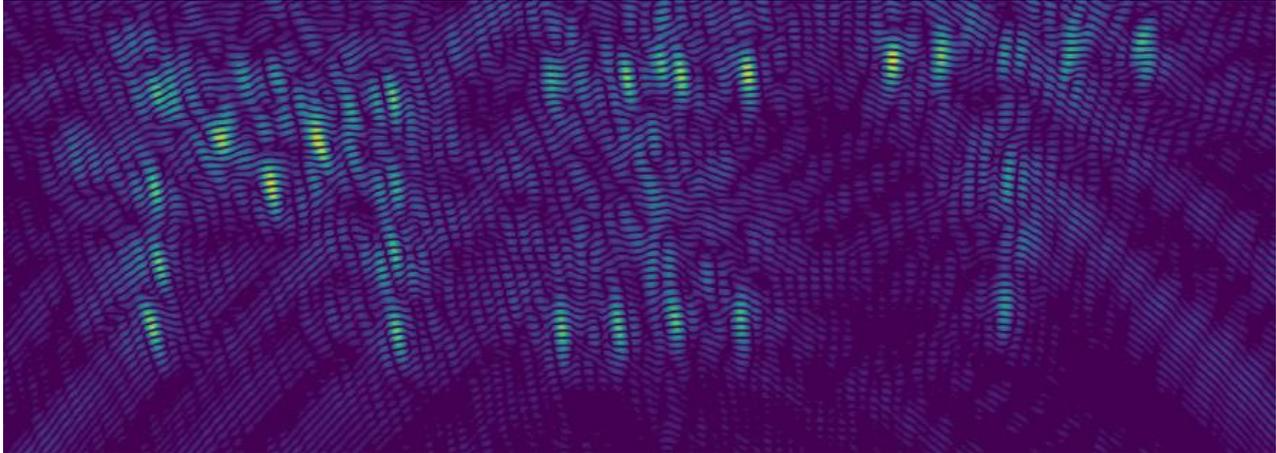
Program Overview

The recent explosion of unmanned air system (UAS) technology coupled with the miniaturization of electronics opens the door to countless applications and missions. UAVs can provide unparalleled views at sporting events, images of structures are not safely accessible to construction workers, and scenic aerial photography, all using low-cost camera technology. One can also envision many applications of small UAS-based radar solutions, ranging from day/night autonomous tracking of objects of interest in all-weather conditions to change detection using radar imaging techniques to search and rescue.

In 2018, the BWSI Unmanned Air System – Synthetic Aperture Radar (UAS-SAR) program will offer students the opportunity to explore the field of radar imaging by building and flying a radar on a small UAS and using it to image objects around campus. The program consists of two components: (1) online course from January to May 2018, open to all interested and committed students, and (2) a four-week summer program at MIT campus for a small group of students from July 9–August 5, 2018. The online course will help students build a solid foundation in the fundamentals of radar, basics of Python programming, and collaboration tools such as Git. During the summer, students will work in small teams of 4 – 5 alongside instructors to build a UAS, implement command and control of a commercial radar, develop radar imaging software, conduct data collections, perform data analysis to identify and address problems, and extend their UAS-SAR system w/ novel capabilities.



UAS-SAR System in Operation



SAR Image of “MIT” formed by Student Team

Online Course

The online component for the BWSI UAS-SAR course contains important introductory material to provide students with the background required to successfully complete the four-week summer course. In addition to the introductory material, the online course will expose students to real-world radar data and UAV motion properties.

Introduction and Prerequisites

- Introduction to Python
- Introduction to Numpy, Matplotlib, and other required Python packages
- Git and GitHub collaboration tools

Radar

- Fundamentals of radar
- Radar system components
- Ranging w/ a radar
- Doppler effect

Summer Course

The four-week summer component of the UAS-SAR course will feature a mix of lectures from radar experts, team-based system development, and real-world experiments with mini-capstone milestones at the end of each week. Lectures w/ active student participation in the form of Jupyter notebooks will reinforce basic radar concepts and dive deep into the principles behind radar imaging. Students will conduct real-world experiment by defining experiment objectives and plans, executing said plans, and performing analysis on the collected data. They will also learn how to interpret radar imagery in order to assess success and areas for improvement in their systems.

Week 1: Let’s Build a Radar

- Python review
- Radar fundamentals review
- Implement radar command and control

- UAS construction
- Milestone: Ranging and Doppler experiments w/ show-and-tell

Week 2: Let's Form an Image

- Introduction to SAR imaging
- Implementing SAR via backprojection
- Rail-SAR experiments
- Milestone: Best SAR image challenge

Week 3: Up, Up, and Away

- Integration of radar onto UAS
- UAS-SAR data collections
- Refining SAR imaging algorithms
- Milestone: Best UAS-SAR image challenge

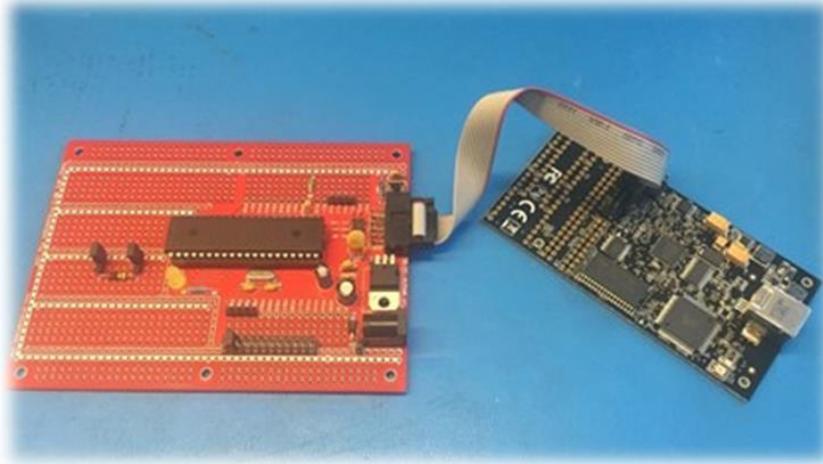
Week 4: Best Image

- Teams refine/improve their UAS-SAR
- Team develop novel capabilities for their UAS-SAR
- Teams compete to form the best image of a secret challenge scene

MIT Beaver Works Summer Institute

2019 Summer Program:

Embedded Security and Hardware Hacking – MITRE Project



Program Overview

Most of us are aware of our reliance on computers throughout our everyday lives, but what we typically think of as computers (from the servers that run our favorite websites, to our laptops and smartphones) are only the tip of the iceberg. Hidden just beneath the surface is a substantial and diverse group of computers referred to as embedded systems. Although the concept may be unfamiliar to many, embedded systems are pervasive and have existed for decades. They commonly work within larger pieces of technology, performing specific tasks, such as operating one element of a car, medical device, aircraft, or even a musical instrument. Their security affects the security of the larger system. And they are being hacked!

This program consists of two components: an online course from January to May open to all interested students, and a four-week summer program at MIT from July 8 to August 4 for a select group of students.

The online course will introduce the students to several security topics with a focus on threats that are especially concerning for embedded systems. These topics include embedded software security, JTAG and UART probing, side-channel analysis, and fault-injection. This background will help prepare students for the summer course, during which they will design and perform security assessments of multiple implementations of an embedded system. They will learn the basics of embedded security and hardware hacking by designing a secure system and performing security assessments of classmates' designs to see who can find and fix the most security flaws.

Online Course

The online component for the Embedded Security and hardware hacking course contains important introductory material to provide students with the background required to successfully complete the four-week summer course.

The online course will consist of the following modules:

- Hardware
- Embedded Software
- Programming in Python
- C programming
- Assembly
- Cryptography Basics

Summer Course

The four-week summer program is based on the MITRE Collegiate eCTF, which challenges teams of undergraduate and graduate students to design a secure system. Teams of BWSI students will design and implement their own secure systems based on a previous eCTF challenge and then hunt for security flaws in other teams' designs. The course will consist of a mix of lectures and hands-on labs and projects that reinforce and apply the material. The detailed topics for each week are listed below:

Week 1: Cryptography and Security

- Overview of cryptography and secure design fundamentals
- Introduction of the design challenge

Week 2: Embedded Software

- Components of embedded systems
- Embedded software security basics

Week 3: Hardware Analysis

- Hardware and interface analysis
- Introduction to side-channel analysis and fault attacks

Week 4: Hack!

- Teams will compete to see who can score the most points – earned by capturing virtual “flags”, by demonstrating flaws in the target systems, and by fixing the flaws to secure the system.

MIT Beaver Works Summer Institute

2019 Summer Program: Hacking a 3D Printer



Hack A 3-D Printer

Program Overview

Additive Manufacturing (AM), and in particular 3D printing, has become a powerful tool in scientific, engineering, and industrial applications. As the technology becomes more pervasive, we continually look for applications and ways to use these tools in innovative ways. One of the key advantages to the open nature of this technology is the ability to modify a printer to operate in a way that was not originally intended.

In summer 2019, BWSI will host the new Hack a 3D Printer course. The goals of this course are to introduce the fundamentals of 3D printing, show how hardware and software can be tuned for optimal performance, and teach techniques to modify these components to do something completely new. Along the way students will learn how to use engineering skills to tackle a difficult problem.

Teams of students will spend four weeks at MIT building, coding, using, and hacking their own 3D printers. The first week will be dedicated to the “nuts and bolts” of AM as students build their own printers. When the printers are complete, students will learn how to use and tune these devices. The second week is dedicated to engineering and design principles as students tackle a number of team-based challenges. Using computer-aided design (CAD) the students will need to design and 3D print their own solutions to problems inspired by real life. Week 3 will focus on hardware and software modifications to the printers they have built. Starting with small instructor-led tweaks to improve performance, the students will ultimately plan a major hardware modification to their printers. The final week is dedicated to implementing their hardware modification, and designing and printing an engineered solution with their “hacked” printer.

Online Course

Before arriving on campus students will be required to complete an online course on AM. The course will introduce students to key math, science, and engineering concepts that will be required on day one. A large portion of this online course will be dedicated to CAD, and students will be required to submit completed CAD drawings.

Introduction and Prerequisites

- Introduction to Additive Manufacturing
- Geometry and Coordinate Systems
- Introduction to Materials Science

Computer Aided Design (CAD)

- Introduction to CAD
- OnShape Tutorials

Summer Course

During the four-week on-campus course, students will learn the details of AM primarily through hands-on activities and experimentation. Daily lectures will provide information and direction, but students will need to apply sound reasoning to solve a variety of engineering challenges. Guest lecturers from MIT and Boston-area companies will help provide context and specific applications of these technologies. Visits to MIT labs using AM and other emerging technologies will be included.

Week 1: Building a 3D Printer

- 3D printer hardware build
- CAD review
- Slicing and g-code
- Printer tuning and optimization

Week 2: Engineering Design Principles

- Designing with constraints
- Limitations of material properties
- Working with a customer
- AM in the real world

Week 3: Printer Modification

- Novel materials
- Advanced CAD and slicing
- Customizing g-code

Week 4: 3D Printing Challenge

The final week will be dedicated to implementing and optimizing a major printer modification. Using the modified printers, students will develop a solution to an engineering challenge.

MIT BeaverWorks Summer Institute

2019 Summer Program: Remote Sensing For Crisis Response



<https://www.af.mil/News/Article-Display/Article/116782/rescue-center-members-assist-with-saving-330-lives-in-tennessee/>

Program Overview

Imagine coordinating a response after the chaos of a hurricane or the challenges of a famine lasting years, these big problems require big data to solve. With airplanes and satellites, we collect mountains of data of affected regions but who looks at this data? How do we turn this data into a physical response? The program's goal is for participants to explore, leverage, and transform open source information and imagery collected from drones, airplanes, helicopters, and satellites to generate actionable intelligence to support a disaster or humanitarian response. Students will be exposed to three main components: 1) feature extraction from raw data, 2) classification via machine learning techniques, and 3) data products for decision makers. The program will explore tools and techniques using real world operational data collected from across the globe.

In 2019, this new BWSI Remote Sensing program will offer students the opportunity to explore the exciting intersection of data science and crisis response. The program consists of two components: (1) online course from January to May 2018, open to all interested and committed students; and (2) a four-week summer program at MIT campus in Cambridge, MA. During the course, the students will learn to understand the basics of Python, Git, machine learning, and image processing through a series of online teaching modules. Students will explore real world datasets ranging from drone imagery of regions to disaster imagery collected by the human volunteers of the Civil Air Patrol. By participating in the online and/or onsite portion of the program, students will develop experience in an area of data science that is poised to play a critical role in understanding our world.

Online Course

Prior to the summer course at MIT campus, students will be required to complete an online course which contains important introductory material. The online course will give the students a strong foundation required to successfully complete the four-week summer course. In addition to foundational introductory material, the online course includes discussion of different use cases and expose students to real world challenges and applications of the coursework.

Introduction and Prerequisites

Computer Science

- Getting started with Python
- Git & GitHub management
- Machine learning perspectives

Data Science

- Advanced NumPy
- Simple image classification
- Introduction to Web Services

Real World Data

- Civil Air Patrol
- USGS Landslide Assessment
- Zanzibar Mapping Initiative

Summer Course

The four-week summer component of aims to guide students through the processing of designing experiments to evaluate primarily text-based content. Daily course material, case studies, guest lectures, and small-group projects will expose students to challenges across technical domains.

The following is a rough outline for the summer course:

Week 1: Foundation

- Python/NumPy/Github review
- Review of machine learning concepts
- Research questions, hypotheses and objectives
- Working with open source tools and data
- Models and metrics; what decision makers are looking for
- Structured vs unstructured data

Week 2: Annotation

- Human vs machine techniques
- Feature extraction and preprocessing
- Beginner/Intermediate machine learning

Week 3: Exploitation

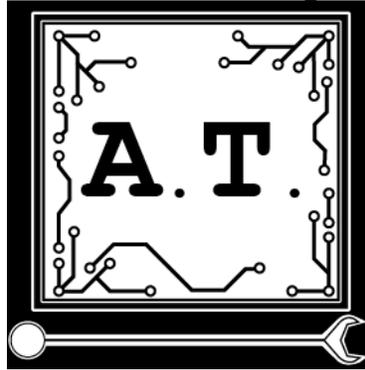
- Feature extraction and preprocessing
- Image analysis
- Metadata analysis

Week 4: Challenges and Use Case

- Apply what you learned and develop data products using real world data!

MIT BeaverWorks Summer Institute

2019 Summer Program: Assistive Technologies (AT)



Program Overview

There are many members of our communities who live with physical and cognitive disabilities, some of whom may be helped by assistive technologies (AT). However, these technologies often need to be customized for the individual, making it difficult to simply use off-the-shelf products. This course will help students develop product design, rapid prototyping, and product testing skills in a user co-design manner to understand how to produce these kinds of solutions.

We will first go over product design processes and exercises in general, and then bring those into the context of working in the assistive technology space. Using example problems and working with community co-designers with disabilities, we will learn how to conduct co-designer interviews to develop product requirements, and how to develop those requirements into prototypes. With early prototypes, we then look at how to iterate over different designs, taking user feedback into account in order to arrive at AT solutions that work well for the end-user.

Online Course

Before arriving on campus students will be required to complete an online course introducing assistive technology, product design, and specific technical skills. The course will introduce students to key math, science, and engineering concepts that will be required on day one. The latter portion of the online course will be an open-ended design activity that will integrate the lessons on design thinking and the technical skills they learned in the earlier portions of the course.

The online course will consist of the following modules:

- What is assistive technology?
- Design thinking
- Design processes
- Technical skills development
- Open-ended design activity

Summer Course

The four-week summer component of BWSI AT will give students a chance to use and further develop what they learned through the online course, with lectures and hands-on design exercises, culminating with teams of students developing two AT solutions for challenges posed by a community co-designer with a disability. The first challenge will have the teams carefully stepping through the design process, working towards a known solution, while the second will be more open-ended, and push teams to work creatively to build something completely novel in an iterative way.

A team of MIT researchers and students will help students through these materials and activities, using previous AT solutions developed at MIT as guiding examples. Co-designers will also be present to help students evaluate their products and provide additional feedback. By the end of this course, students will have developed an understanding of the engineering process that it takes to build an AT solution, be able to identify engineering requirements from user interviews, be able to identify potential solutions and the skills required to implement the solutions, and build their own prototype solutions.

This course is new for the summer of 2019 and is still under development. The focus of the technology skills component in particular will depend on the co-designer's challenge and is subject to change, but may include areas such as computer-aided design, 3D printing, and electronics. Past projects that have come out of a similar MIT class and hackathon have included all-terrain walkers, jackets that can be zipped up with one hand, a device to control smartphones using sip-and-puff breath inputs, and others.

Week 1: Product Design Introduction

- Interviewing users and identifying requirements
- Working with people with different disabilities
- Rapid prototyping using basic materials
- User testing and learning from tests
- Documenting designs

Week 2: First Challenge

- Co-designer introduction
- Examining proposed solutions and required skills
- Build and present solutions

Weeks 3-4: Second Challenge

- Co-designer introduction
- Brainstorming, planning, and presenting initial ideas
- Build and present solutions
- Prototype testing and evaluation by co-designer
- Tweak, rebuild, refine, reevaluate
- Present final products

BWSI Online Program Application Process

The Beaver Works Summer Institute is pleased to announce that we are expanding our program offerings for summer 2019. The following programs will be offered:

- Autonomous RACECAR Grand Prix
- Autonomous Air Vehicle Racing
- Hacking a 3D Printer
- Cog*Works: Build Your Own Cognitive Assistant
- Medlytics
- Embedded Security and Hardware Hacking
- Build a Cubesat
- Unmanned Air System–Synthetic Aperture Radar
- Assistive Technologies
- Remote Sensing for Crisis Response

To apply to one of these summer programs, you must complete the BWSI Online Education Program, designed to prepare students for the technically rigorous BWSI summer programs. To participate in the online course, a student must submit the following:

1. A nomination by a school technical point of contact (POC), typically a STEM teacher or school administrator familiar with the student's schoolwork and technical abilities. The nomination form for the teacher/recommender can be found at https://mit-bwsi.formstack.com/forms/bwsi_recommendations_onlinecourse_2019
2. The application form for the student will be sent to them once the request comes in from the teacher/recommender.
The official courses do not start until Late January 2019 and you will not be able to enroll in them until then. At that time if your application is approved, the student will receive an email containing a user ID and password as well as instructions on how to access the online course website.

Teachers, prior BWSI students, and teaching assistants (TAs) can also apply for online course access by using the same [BWSI online course](#) request link and filling out the form.

BWSI Summer Program Application Process

Application for the BWSI Summer Program is separate from the online course application. The Summer Program application will be available Mid-Late March 2019, with decisions expected 30 April 2019. The selection criteria for the Summer Program include, but are not limited to,

1. Demonstrated technical ability (determined through recommendation by school official and other supporting information, such as test scores, completed coursework, and grades collected in the application).
2. Demonstrated commitment to extracurricular learning via participation and completion of the online course (participation/progress are tracked by the instructors).

Students must make significant progress in the online course by Summer Program application to ensure that they are ready and well prepared for participation in the BWSI programs. Students may participate in one or more of the online courses to determine which they are interested in, but note that the online courses are time-intensive, and we suggest down selecting to a single course as early as possible.

Beaver Works Summer Institute (BWSI) RACECAR Remote/Travel Team Participation Guidelines and Recommendations

Four remote teams, including three from Mexico and one from Canada, completed the BWSI 2018 RACECAR program and one from Nauset Massachusetts completed the BWSI 2019 Unmanned Air System – Synthetic Aperture Radar program. The teams were able to follow the same curriculum as the MIT class, travel to Cambridge, and successfully participate as peers in the final challenge events at MIT. On the basis of their experiences, we have formulated guidelines and recommendations for teams who might be interested in participating remotely. This option may be beneficial to international schools; and to schools contemplating adopting or offering the program in their own curriculum, increasing the number of opportunities for their students to participate in the program. We assume a certain level of familiarity with the overall program and curriculum in particular, in the descriptions below. It may also be helpful to review the BWSI Program Brochure and Admission Procedures materials for additional background and context.

Overview

Your students can be prepared to participate in the BWSI course by completing the prerequisite online content we provide and require of all prospective applicants. When the summer program begins, students are able to follow along with the summer program “live” by using the same content we teach in our classroom. For the RACECAR course the final Grand Prix track layout and design of special features intended to technically challenge and demonstrate the student teams’ skills is revealed at the start of the fourth week of the RACECAR course. The entire fourth week is a “build week” during which the teams design, build, integrate, and test their systems and component implementations. We have instructors, mentors, and coaches available to support teams throughout the process by answering and asking questions, observing team interactions, and offering helpful tips (without providing solutions). Remote teams are also welcome to attend during this week to build their implementation, interact with other students, observe other teams, and benefit from our support. All teams participate in the weekend Final Challenge Demonstration events.

Online Preparation

New and updated content is made available during January in our online EdX course that all prospective students are required to complete for admission or participation in the summer program. The course is organized into topical modules that cover technical subjects of interest and then develop skills needed to work on the BWSI programs. The course is intended to ensure all students arrive with a common baseline set of skills and exposure to technical topics that we can build upon in the summer program.

The online content enables students to begin the learning process. For the RACECAR course instructions are provided to install, operate, and program a model RACECAR in a simulated environment using the same tools and interfaces as the physical vehicle. We include sensor simulations and model “worlds” of previous BWSI final challenge tracks and others that have been used in MIT courses.

Prior course content, much of which will be reused remains available for access by anyone with registered credentials at <http://bwsix.mit.edu/>. We work through single designated points of contact at each school to set up and verify access to this site for local instructors and individual students.

Summer Program Curriculum

Once the summer program begins, we release the in-class content as it is delivered in the classroom. To facilitate that process in BWSI 2017, we created a BWSI RACECAR 2017 module in our online course and updated and added links to the content for lectures, labs, and demonstration challenges in the weekly topic sections, each day. This was the same mechanism used to release the content to the MIT BWSI students to ensure everyone whether local or remote, received identical material at the same time. The content is primarily in the form of links to streaming and recorded lectures, lecture slides and notes, hands-on lab handouts, sample code snippets, and end-of-week challenge descriptions from the 2017 program, which are still available for reference.

It is essential that remote/travel teams have local instructional and mentoring support for the preliminary on-line preparation, and hardware/software build/installation process, especially during the summer program itself. We recommend that prospective instructors and mentors go through the online course themselves and/or are otherwise prepared to support their students in understanding the content. Some schools have established relationships with MIT or a local university with departments that have students who may be recruited for internships as effective in-class or afterschool mentors for their teams.

Build Week and Final Event Participation

We recommend teams arrive at least three days before the Final Challenge event and are welcome to spend the entire “build week” with us. Early arrival ensures teams have sufficient time and opportunity to become acclimated, verify their hardware operation, and build/design/test their software implementation against the specific technical challenges under representative conditions that they will encounter in the final event. This week is very intensive for all teams, and while we generally have an instructor, mentor, or coach for every team, demands on their time and attention are high.

Guidelines and Requirements

These requirements are intended to ensure that all teams have the same working hardware configuration, software architecture with required capabilities, and level of preparedness needed to succeed in the build week and Final Challenge event.

Your student team(s) must build or buy a RACECAR that matches specifications of the summer program vehicle. Those specifications (bill of materials, laser cutting files, and assembly guide) are publicly available and the parts cost of a typical build is approximately \$5000. Assembly time varies with experience but is typically on the order of 8 hours for someone with basic mechanical and soldering skills using the guide we provide.

The proper operation of the vehicle must be demonstrated using the baseline software provided for the summer program before arriving at MIT. We can only provide very limited diagnostic and repair support for vehicles. We recommend teams bring a selected set of spare parts and a tool kit with them that reflects on their past experience building, operating, and maintaining their own RACECAR.

Logistics

Housing must be arranged for your students. Area hotels are available and home stay options may be possible if family relatives or sponsors live in the local area. We can provide no support for finding or making such arrangements or any transportation required to attend the program for remote/travel teams.

For international teams from institutions who participate in the MIT MISTI program, you may already have a MISTI program point of contact who could help with logistics and possibly recruit mentors from the MIT community to support your teams.

We do not arrange for visas required for travel, but can supply or sign documentation that explains the purpose for the trip.



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