MIT Beaver Works Summer Institute
Summer 2017

Autonomous RACECAR Grand Prix

Autonomous Air Vehicle Racing

Autonomous Cognitive Assistant
The MIT Beaver Works Summer Institute (BWSI) is a rigorous, world-class STEM program for talented rising high-school seniors. In its first year in 2016, the program featured an intensive, hands-on, project-based challenge through which the students learned how to navigate an autonomous mini-racecar through a complex environment. This program culminated in a final race day when the students put their new skills and knowledge to the test against the clock.

The first year of BWSI was a complete success thanks to the enthusiasm of our students, the dedication of our instructors, and the hard work from our team members. The Institute partnered with 24 high schools across the nation to recruit the future engineers who participated in our program. We had the pleasure of working with 46 students, 24 of them joining us from outside Massachusetts.

This year, we are very excited to be expanding the opportunities for students, with a larger class of RACECAR summer students, with two brand new courses in Autonomous Air Vehicle Racing and Cognitive Assistants, and with companion online courses that cover prerequisites for the summer programs. We hope that early-adopting high schools will implement our program’s courses for their students and join the final competitions. These courses are designed to be just the beginning of the national and then international expansion of engineering education we want BWSI to spark.

In the coming years, we will be adding new BWSI courses in a range of disciplines to increase participation substantially and to build a model that high schools and universities can emulate. While creating a network of these institutes across the nation and the globe, we will support high school STEM teachers who want to use our teaching materials to help better prepare their students for college and potential future careers. We want this network of institutes to work together to bolster engineering education nationally and internationally and provide more opportunities for students interested in STEM fields.

Thank you for your continued support of our program.
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.
2017 MIT Beaver Works Summer Institute
(July 9 – August 6, 2017)

Autonomous RACECAR Grand Prix

Autonomous Air Vehicle Racing

Cog*Works: Build Your Own Cognitive Assistant
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 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, 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 9 to August 6 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 using 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 lecturer’s 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.

Introduction and Prerequisites

- Installing and using the virtual machine
- Overview of the Ubuntu/Linux environment
- Basics of Python programming
- Introduction to the Robot Operating System

Autonomous Vehicles

- Using the RACECAR model in the Gazebo simulation environment
- Basic control systems
- Fundamentals of computer vision using the OpenCV library
- Elementary navigation and planning concepts
Summer Course

The four-week summer program is based on the BWSI 2016 course, with the addition of the 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 over the August 5–6 weekend. A wide variety of challenges will require that a range of behaviors be implemented to make high-level decisions based on visual perception in order to complete a circuit of the track.
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 design their own autonomous capabilities for UAVs. The students will work in teams to develop algorithms for deployment to a commercial quadrotor, the AR Drone 2.0. They will use the Robotics Operating System (ROS), various open-source libraries, and custom algorithms that they will develop. 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 9 to August 6 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. The skills the students develop during the summer will be demonstrated in a simulation environment as well as on an AR Drone 2.0. 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.
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 in 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 each day, 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 AR Drone 2.0 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 curriculum is new this year and is still in development at this time, but the current plan extends over three 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: Control
- Control systems
- State estimation
- Navigation and planning

Week 3: Vision
- Image formation
- Edge detection
- Image filtering
- Object detection

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.
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 new 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., IBM’s Watson services) 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 2017, open to all interested and committed students and (2) a four-week summer program at MIT for a small group of students, July 9–August 6. During the course, the students will be trained to understand the basics of Python, Git, natural language processing, machine learning, and IBM Watson services 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

- Getting started with Python
- Managing your work using Git & Github
- Perspectives on machine learning

Autonomous Cognitive Assistants

- Advanced NumPy
- Simple image classification with Python
- Introduction to neural networks
- Introduction to Web Services
- Learning IBM Watson®, 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: Hello World

- Detailed review of the online course
- Python, NumPy, object-oriented programming
- Git/GitHub
- Perspectives of machine learning
- Project: Create your own "autograd" back-end

Week 2: Learning

- Hands-on machine learning: classifiers
- "Autograd" technologies (TensorFlow, Theano, PyTorch, etc.)
- Neural network frameworks (Lasagna, Keras, PyTorch, etc.)
- Survey of speech-to-text technologies
- Project: Build your own speech-to-text-to-command pipeline

Week 3: Assistants

- Survey of cognitive assistant technologies (Watson, Cortana, Alexa, Siri, etc.)
- Under the hood of cognitive assistants
- Project: Create a custom framework for your own cognitive assistant

Week 4: Challenges

In the final week of the course, teams of students will work toward a capstone project challenge: creating a customized cognitive assistant using components built in Weeks 1–3 and the online course
Online Program Application Process

The Beaver Works Summer Institute is pleased to announce that we are expanding our program offerings for summer 2017. Three programs will be offered:

- Autonomous RACECAR Grand Prix
- Autonomous Air Vehicle Racing
- Cog*Works: Build Your Own Cognitive Assistant

The first step in applying to one of these summer programs is completing 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.
2. The application form at the Beaver Works Summer Institute website and the required permission forms. In order to apply, you must request the password from your school administrator.

Once the 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 (TA) can also apply for online course access by using the same BWSI webpage and choosing the appropriate category from the pull-down menu.

Application for the BWSI Summer Program is separate from the online course application. The Summer Program application will be available mid-February 2017, with decisions expected in early April 2017. 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 and progress are tracked within the online course educational modules).

Students must make significant progress on the online course by March 2017 and continue their online course work into spring 2017 in order to be ready and well prepared for participation in the BWSI programs. Students may participate in one or more of the online courses to determine which summer course they are interested in, but note that the online courses are time-intensive, and we suggest downselecting to a single course as early as possible.
Summer Program Application Process

All students enrolled in the BWSI Online Program will receive an email invitation with a link to the summer program application. If you are a student currently enrolled and actively participating in the BWSI online course of study, please check the email you used to register and access the online program website, including your spam folder. If you did not receive an invitation email to apply to the 2017 summer program, please notify us at bwsi2017-application@mit.edu

Please read the instructions below carefully. Student applicants are required to forward the summer application invitation email to the teacher or school administrator who will be providing their recommendation. This step can be done at anytime, but please give your teacher/school administrator adequate time to complete the recommendation prior to the deadline of Friday, April 7, 2017. Complete the application, including essays, prior to submission. Do not submit duplicate applications as doing so may delay consideration of your application.

Please submit your completed application and supporting essays no later than Friday, March 31, 2017, and have your teacher/school administrator submit their recommendation no later than Friday, April 7, 2017. Please refer to the checklist below for date-sensitive instructions.

Prior to applying, please discuss the program requirements with your parents and teachers. The BWSI program is a four-week commitment, and we want to ensure that all selected students will dedicate the entire four weeks to the program. The program this year will run from Sunday, July 9, 2017, to Sunday, August 6, 2017.

Your participation in the BWSI Online Program is a prerequisite and major component of admission. The student applying for the summer program must have started the online course(s) prior to applying, and must have completed it prior to the summer program start date.

You and your team’s success and enjoyment within the program are predicated on each student arriving at MIT well prepared academically for the advanced program content.

If you do not believe you meet the prerequisites, or will have difficulty completing the online course prior to the start of the summer program, please speak with your parent(s), school BWISI coordinator, and/or teachers.
Important Summer Program Dates and Deadlines

Student Application Deadline:  Friday, March 31, 2017 at 11:00 PM EST

Recommender Deadline:  Friday, April 7, 2017 at 11:00 PM EST

Decisions Released:  Sunday, April 30, 2017 via student email

Program Dates (Residential Student):  Sunday, July 9, to Sunday, August 6, 2017

Program Dates (Day/Local Students):  Monday, July 10, to Sunday, August 6, 2017

General Program Information

1. The program is free of charge, except that all students are responsible for the planning and cost of their own transportation to/from MIT.
2. The three BWSI programs will run concurrently during the dates shown above.
3. Class is from 8:45 AM – 5:00 PM, Monday – Friday.
4. Students are expected to be at their assigned MIT classroom no later than 8:45 AM each day, prepared for class.
5. Students will have nightly homework.
6. Students will be required to provide their own laptop computer. If there is a hardship, please contact BWSI Staff at bwsi2017-application@mit.edu after you have received your application decision.
7. Residential students from out-of-state high schools are provided room and meals in dormitories on MIT campus. They will be supervised by BWSI Instructor Staff during the day and by BWSI Residential Counselors during the evenings and weekends.
8. Students from local high schools are required to provide their own transportation to/from MIT campus for all scheduled classes and events. BWSI Staff will not be responsible for students transiting to/from MIT, and outside of normal program hours of Monday – Friday, 8:45 AM – 5:00 PM.
9. Each Wednesday night, there will be a BWSI Social Dinner held at MIT for both residential and day students, and program staff.
10. Complete program details and forms (minor consent, medical, waivers) will be sent out shortly after admission decisions.
Summer Program Application Process (continued)

BWSI Summer Program Application Instructions

1. Participants in the BWSI Online Program will receive an email inviting them to apply to the 2017 BWSI Summer Program. Please follow the ‘Begin Application’ link to start your application only after you have read the complete application instructions contained here.
2. Applications and essays are due no later than Friday, March 31, 2017.
3. Teacher recommendations are due no later than Friday, April 7, 2017. Only one (1) recommendation per applicant is allowed.
4. The student is required to forward the summer application invitation to the teacher or school administrator who will be providing their recommendation. This step can be done at anytime, but please give your teacher/school administrator adequate time to complete the recommendation prior to the deadline.
5. Indicate your 1st, 2nd, and 3rd course choices on your application. We will make every attempt to honor your 1st choice, but if space is limited, we will consider placement in your 2nd or 3rd choice. Only indicate a choice for programs that you are actually interested in attending.
6. Finish the application, including essays, prior to submission. Do not submit duplicate applications as doing so may delay consideration of your application.
7. Write your three essays prior to starting the online application, and copy and paste your essays into the corresponding fields within the application. The three essays you must include (500 words or less) are
   1. Essay #1: Explain how you became interested in science and engineering, and what your career goals are.
   2. Essay #2: Explain how participating in this program will support your academic and career goals.
   3. Essay #3: Write about a news story that you have seen or read recently that relates to science and engineering, and explain why you found it interesting.
8. Admission decisions will be sent out on April 30, 2017, via email.

Application Check List

1. Complete essays as outlined in the application instructions above.
2. Instruct your teacher to submit recommendation by forwarding invitation email.
3. Complete and submit application, with essays.