Deep Learning-Based Self-Driving Robots Summer Camps

# Course Description:

Self-driving will increase productivity, independence, and safety in our society. There are two significant challenges in today’s self-driving: the deployment and evaluation of learning algorithms in autonomous vehicles are risky, expensive and incur considerable liability in personal and property safety, and the second challenge is the lack of workforces who are familiar with the required machine learning and deep learning and work competently in designing highly reliable AI algorithms that far exceed human drivers.

Self-driving vehicles and robots often have a steep learning curve and need years of education and training. In this summer camp, we tried to turn the tables and ease the K-12 STEM training in self-driving and artificial intelligence. We will turn complicated learning processes into playful interactions with each other’s kids' self-driving robots that motivate and inspire you, future leaders, to acquire knowledge and expertise with hands-on experience and peer-to-peer friendly competition.A picture containing indoor

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In this camp, you are provided with a low-cost, open-source self-driving vehicle that enables the safe and rapid development of Python-based AI and deep-learning algorithms for autonomous driving. In the summer camp, you will turn your cell phone into an intelligent robot to control the provided platform. You will directly work with scaled-down dynamics, sensing, decision-making, controls, and safety issues in real-life autonomous vehicles.

Once you complete this training, you will continue to apply your acquired deep learning knowledge in your daily life and future college endeavors.

# Course Logistics

Location CEWIT 200

Time 9:30 AM-4:30 pm (One-hour lunch break in CEWIT 200 with your own food).

You need to bring your personal laptop (Microsoft Windows)

Instructor Team Yu Sun, Zeyu Dong, Kevin Mahon, Giorgian Borca-Tasciuc, Nick Hanson,

and Professor Dantong Yu (Lead Instructor)

# Required Textbook

[Free Online Material] Dive into Deep Learning: <https://d2l.ai/>: Cambridge University Press 2023, used by 500 Universities in more than 70 countries.

# Required Lab Scripts Chapter 2-Chapter 8:

https://github.com/d2l-ai/d2l-pytorch-colab: Chapter 2 to Chapter 8.

# Course outcomes:

1. Apply deep learning concepts, methodologies, and frameworks to solve real-world problems.
2. Develop and apply critical thinking, problem-solving, and decision-making skills needed for deep learning.
3. Learn how to use open-source machine learning tools (PyTorch) to solve real-world self-driving problems.

# Prerequisites

Basic programming knowledge and skills.

A reasonable understanding of statistics.

GPA: 3.5+

# Your Daily Schedule

9:00 AM - 9:30 AM (30 Minutes) Arriving and check-in

9:30 AM -10:30 AM (60 Minutes) Lectures in Deep Learning/Self-Driving

10:30 AM-11:15 AM (45 Minutes) Start the Car/Check/Drive/Training

11:15 AM-12:00noon (45 Minutes) Companion Python Notebooks for Deep Learning

12noon-12:30 PM Lunch Break

12:30 PM-1:30 PM Free Activity Option: take a break, drive car/team building/training

1:30 PM-2:15 PM (40 Minutes) Lectures in Deep Learning/Self-Driving

2:15 PM-3:30 PM (75 Minutes) Driving Car/Training Scripts

3:30 PM-4:15 PM (45 Minutes) Companion Python Notebooks for Deep Learning

4:15 PM-4:30 PM (15 Minutes) Q&A/Wrap Up

4:30 PM-5:00 PM (30 Minutes) Check out and leave the building

# Daily Content/Activities

#### Day 1. Learn about F1/10 Autonomous Driving Vehicles and get hands-on experience driving a real radio-controlled vehicle both indoors on a track and off-track corridor, as well as outdoors. You can even practice and control the car from your desk.

#### Day 2. Introduction to Deep Learning and Self-Driving System Break Down: Traxxas 1/10 RC Car, Cell Phone-based embedded computer, hardware components, programming environment

#### Day 3. Python programming basics and Machine Learning Basics (D2L Chapter 2: Linear Algebra, Probability, and Gradient Descend)

#### Day 4. Linear neural networks for Regression and Classifications (D2L Chapters 3 & 4)

#### Day 5. Multilayer Perceptron (D2L Chapter 5 MLP)

#### Day 6. Deep Learning Regularization (D2L: Chapter 5 MLP)

#### Day 7. Convolutional Neural Networks for Self-Driving (D2L: Chapter 7 CNN)

#### Day 8. Advanced Convolutional Neural Networks for Self-Driving (D2L: Chapter 8 Advanced CNN)

#### Day 9. Attention Networks, How do we connect Today’s AI, Large Language Model (Out-door-parking lots)

#### Day 10. Parents' Day, Robotic Racing Competitions (Fast, Furious, and Safe) on-track and off-track, and graduation and certification ceremony

# Program Structure

#### Day 1. Learn about F1/10 Autonomous Driving Vehicles and get hands-on experience driving a real radio-controlled vehicle both indoors on a track and off-track corridor, as well as outdoors. You can even practice and control the car from your desk.

#### Morning

#### Welcome talk (Yu Sun) (9:30 am - 9:45 am)

#### Introduction to Self-Driving (Professor Dantong Yu - One hour) (9:45-10:45 am)

#### Half an hour ice breaker. Two truth and a Lie (10:45-11:15 am)

#### Practice car control (11:15am-noon)

#### 1- hour Lunch Break

#### Afternoon

#### Finish up Introduction to Self-driving (1 pm-2 pm)

* Continue practicing car control (2 pm-3 pm)
* Break (10 mins)

#### Introduction to Machine Learning. (Professor Dantong Yu) (3:10 pm-4:15 pm)

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#### Day 2. Introduction to Deep Learning and Self-Driving System Break Down: Traxxas 1/10 RC Car, Cell Phone-based embedded computer, hardware components, programming environment

In just the past few years, deep learning has taken the world by surprise, driving rapid progress in such diverse fields as computer vision, natural language processing, automatic speech recognition, chatGPT, reinforcement learning, and biomedical informatics. Moreover, the success of deep learning on so many tasks of practical interest has even catalyzed developments in self-driving. With these advances in hand, we can now build cars that drive themselves with more autonomy than ever before (and less autonomy than some companies might have you believe), innovative reply systems that automatically draft the most mundane emails, helping people dig out from oppressively large inboxes, and software agents that dominate the world’s best humans at board games like Go, a feat once thought to be decades away.

* Finish up the machine learning presentation (9:30 AM-10:30 AM)
* Driving practice on indoor tracks and corridors **to collect your initial training data**. If time permits, it is optional to drive in the outdoor area in the CEWIT backyard (10:40 AM-11:40 AM)
* Introduction to Deep Learning (Dantong Yu) (11:40 AM-12:30 PM)

Lunch break and Students can play with the car during their break. (12:30 PM-1:30PM)

* Finish up Deep Learning (Dantong Yu) (1:30PM-2:20PM)
* Go through some Google Colab scripts that are accompanied by the morning deep learning. (One hour with Zeyu Dong) (2:30pm-3:30pm) PyTorch quickstart for beginners (<https://colab.research.google.com/github/pytorch/tutorials/blob/gh-pages/_downloads/af0caf6d7af0dda755f4c9d7af9ccc2c/quickstart_tutorial.ipynb>)
* Late in the afternoon (3:30PM-4:30PM): We will hold on-track races in the CEWIT 200. The winner will be determined by who is the fastest while staying on track and avoiding collisions with obstacles. (Judge will be our teacher).

Make competition rules first! Something like:

Time three laps and calculate the average while drive individually

Two teams drive together

#### Day 3. Python programming basics and Machine Learning Basics (D2L Chapter 2: Linear Algebra, Probability, and Gradient Descend)

* One-hour lectures by Dantong on Linear Algebra (9:30 AM-10:30 AM)
* Data Collection (10:30 AM-11:30 AM)
* One-hour notebooks with Giorgian on linear algebra (11:30 AM-12:30 PM)

Lunch break (12:30 PM-1:00 PM)

* One-hour lecture on Statistics (Dantong) (1:00-2:00 pm)
* Additional Data Collection (2:00 pm-3:00 pm)
* One-hour notebooks with Self-driving CNN models (Kevin Mahon 3:00 PM - 3:45 PM)
  + Starting the training of CNN model
* One-hour notebooks with Giorgian on Google Colab statistics. (3:45 PM-4:30 PM).

#### Day 4. Linear neural networks for Regression and Classifications (D2L Chapters 3 & 4)

Before we worry about making our neural networks deep, it will be helpful to implement some shallow neural networks, for which the inputs connect directly to the outputs. This will be important for a few reasons. First, rather than being distracted by complicated architectures, we can focus on the basics of neural network training, including parameterizing the output layer, handling data, specifying a loss function, and training the model. Second, this class of shallow networks comprises a set of linear models, which subsumes many classical methods for statistical prediction, including linear and softmax regression. Understanding these classical tools is critical because they are widely used in many contexts. We will often need to use them as baselines when justifying fancier architectures. This chapter will focus narrowly on linear regression, and the subsequent chapter will extend our modeling repertoire by developing linear neural networks for classification.

* Starting the training of CNN model (9:30 AM-9:45 AM)
* Lectures by Dantong on Linear Regression (9:45 AM-10:30 AM)
* Group collaboration on coming up with objective model evaluation criteria (10:30 AM-10:45 AM)
  + Kevin/Zeyu/Giorgian can have a shared Google doc where the evaluation is brainstormed
* Python notebooks with Giorgian on Linear Regression (10:45 AM-11:30 AM)
* Test the trained models (11:30 AM-12:00 PM)

Lunch Break (12:00 - 1:00 PM)

* Reiterate collecting and upload data (1:00 PM - 2:30 PM)
* Lectures by Dantong on Logistic Regression (2:30 PM - 3:30 PM)
* Break
* Python notebooks with Giorgian on Logistic Regression (3:40 PM-4:10 PM)
* Starting the training (4:10 PM - 4:30 PM)

#### Day 5. Multilayer Perceptron (D2L Chapter 5 MLP)

#### We will introduce your first deep network. The simplest deep networks are called multilayer perceptrons. They consist of multiple layers of neurons, each fully connected to those in the layer below (from which they receive input) and those above (which they, in turn, influence). Although automatic differentiation significantly simplifies the implementation of deep learning algorithms, we will investigate how these gradients are calculated in deep networks. Then we will be ready to discuss issues relating to numerical stability and parameter initialization that are key to successfully training deep networks. When we train such high-capacity models, we run the risk of overfitting. Thus, we will revisit regularization and generalization for deep networks. Throughout, we aim to give you a firm grasp of the concepts and the practice of using deep networks.

* One-hour lectures by Dantong on Multilayer Perceptron (9:30 AM - 10:30 AM)
* If your model is trained, please verify your car model and see how well it works; Otherwise, start training. (10:30 AM-11:00 AM)
* One-hour notebook with Giorgian on MLP (11:00 AM-12:00 noon)

Lunch Break (12:00noon-1:00 PM)

* Model evaluation
  1. We will evaluate everyone’s model together (1:00 pm-2:00 PM)
* Python notebook on the hyperparameters scripts with Zeyu (2:00 PM-2:30 PM)
* Collect training data **with cones** in the target area and further tune up models (2:30 PM-4:00 PM)
* Tune training based on hyperparameters (Optional)
* Project Assignments Preview and Set up training for weekends. (4:00 PM-4:30 PM): you design your self-driving models to handle various driving conditions)**, for example, avoiding pedestrians, avoiding obstacles, jumping over hoops, taking elevators, following hand signs to direct traffic, going into/out of the building,**

* + **Working models for two predefined tracks**
  + **One model for your own idea (own route, research on dataset & model, long route, multiple group cars)**
  + Look at who had the most improvement and who worsened the most
  + Initiate a discussion to explore the reasons behind the improvement and identify what strategies were effective and which ones were not.
    - Also, discuss training data collection strategy and method
  + Students incorporate lessons into their own model
  + Leave some space for collecting more training data
  + Decide which track they are going to choose to collect and train for the final design project.
  + Decide their evaluation metrics. (Model faster).
  + Collect more data on their tracks.
  + Customize and modify the scripts.

Week 2:

#### Day 6. Deep Learning Regularization (D2L: Chapter 5 MLP)

* One-hour lectures by Dantong on Multilayer Perceptron Regularization (9:30-11:15 AM)
* Break (11:15-11:25AM)
* One-hour notebooks with Giorgian on MLP Regularization (11:25 AM-12:30 PM)

Lunch Break (12:30-1:00 PM) and students can continue with Data Collection with Obstacles

**Afternoon**

End-to-End PyTorch Tutorial (1:00 pm-2:00 pm) (Zeyu Dong)

1. Zeyu will program a simple CNN script to allow students to program, modify, and improve the NVIDIA CNN networks models, train and convert the models in Google Colab. Allow them to upload to Cell Phone for training. Students can modify networks, change the loss functions, and watch the process of training (epoch). (1:00-1:40pm)
2. We will discuss all CNN models in the scripts that are used for self-driving (note that we will teach the model details in Tuesday and Wednesday lectures again). (1:40pm-2:00pm)

Model Evaluation (2:00 PM-4:00 PM) (Kevin))

1. Evaluate new the models and create a new leaderboard
2. Look at who had the most improvement and who worsened the most.
3. Initiate a discussion to explore what contributed to the improvement and identify what strategies were effective and which ones were not.
   1. Also, discuss training data collection strategy and method.
4. Students incorporate lessons into their own model.
5. Leave some space for collecting more training data.

TA Session (3:00PM-4:00PM) Overlapping with Model Evaluation (Giorgian).

D2L book

Course Slides

Scripts

End-to-End Self-driving paper discussions (4:00PM-4:30PM). The paper is a Github (2024) Discussion Session.

* + What are the challenges to be solved in the self-driving paper? How well does this paper address these challenges?
  + What are the contributions of this paper?
  + Please list three Strengths of the paper.
  + Please List Three weaknesses of the methods of the paper.
  + What issues should this paper address they did not?

* + How do you improve over this paper and come up with your self-driving systems?

#### Day 7. Convolutional Neural Networks for Self-Driving (D2L: Chapter 7 CNN)

Convolutional neural networks (CNNs) are one creative way machine learning has embraced for exploiting some of the known structures in natural images.

Basic Concepts of Convolution, cross-correlation, padding, stride, pooling,

* One hour and a half lectures by Dantong on Convolutional Neural Networks (9:30 am-11:00 am)
* Data collection, data uploading, model training, and evaluation. (10:30-11:15 AM)
  + Project tips on screen
* One hour notebooks with Giorgian on CNN (11:30 am-12:30 pm)

Lunch Break (12:30 PM-1:00PM)

* Continue on CNN introduction by Dantong Yu (1:00pm-:1:30PM)
* Data collection, data uploading, model training, and evaluation. (1:30PM - 2:30PM)
  + Inspect collected data, especially for groups that do not have good models.
* Model evaluation collection (1:30 PM-2:30 PM)
  + Evaluate new models once the model is ready.
  + Project Assignment Revisit:
  + **Working models for two predefined tracks**
  + **One model for your own idea (own route, research on dataset & model, long route, multiple group cars)**
  + Look at who had the most improvement and who worsened the most
  + Initiate a discussion to explore the reasons behind the improvement and identify what strategies were effective and which ones were not.
    - Also, discuss training data collection strategy and method
  + Students incorporate lessons into their own model
  + Leave some space for collecting more training data
  + Decide which track they are going to choose to collect and train for the final design project.
  + Decide their evaluation metrics. (Model faster).
  + Collect more data on their tracks.
  + Customize and modify the scripts.
* Giorgian will talk about script by Giorgian (2:30 pm-3:00 PM)
* Continue data loading (3:00 pm-4:30 PM)

#### Day 8. Advanced Convolutional Neural Networks for Self-Driving (D2L: Chapter 8 Advanced CNN)

We begin our tour of modern CNNs with AlexNet (Krizhevsky et al., 2012), the first large-scale network deployed to beat conventional computer vision methods on a large-scale vision challenge; the VGG network (Simonyan and Zisserman, 2014), which makes use of many repeating blocks of elements; the network in the network (NiN) that convolves whole neural networks patch-wise over inputs (Lin et al., 2013); GoogLeNet that uses networks with multi-branch convolutions (Szegedy et al., 2015); the residual network (ResNet) (He et al., 2016), which remains some of the most popular off-the-shelf architectures in computer vision; ResNeXt blocks (Xie et al., 2017) for sparser connections; and DenseNet (Huang et al., 2017) for a generalization of the residual architecture. Over time many special optimizations for efficient networks were developed, such as coordinate shifts (ShiftNet) (Wu et al., 2018). This culminated in the automatic search for efficient architectures such as MobileNet v3 (Howard et al., 2019). It also includes the semi-automatic design exploration of Radosavovic et al. (2020) that led to the RegNetX. The work is instructive insofar as it offers a path to marry brute-force computation with the ingenuity of an experimenter in the search for efficient design spaces. Of note is also the work of Liu et al. (2022), as it shows that training techniques (e.g., optimizers, data augmentation, and regularization) play a pivotal role in improving accuracy. It also shows that long-held assumptions, such as the size of a convolution window, may need to be revisited, given the increase in computation and data. We will cover this and many more questions in due course throughout this chapter.

* lectures by Dantong on Advanced Convolutional Neural Networks (9:30 AM-10 AM)
* Break with playing the car models (10:00-11:15 AM)
* One hour notebooks with Giorgian on advanced CNN (11:15 AM-noon)

Lunch Break (12:00 noon-12:30 PM).

* Model training/evaluation/ (12:30 PM-2:00 PM).
* Evaluate new models and update the leaderboard
* Collect more data on their tracks.
* Customize and modify the scripts.
* Continue on Advanced CNN introduction by Dantong Yu (2:00 PM-2:30 PM)
* Giorgian will talk about the script by Giorgian (2:30 PM -3:45 PM)
* Design project data collection, uploading, and start model training (3:45 pm-4:30 PM)

#### Day 9. Attention, Transformer, Large Language Models and Model Training and Testing Day (Out-door-parking lots)

In this chapter, we introduce attention models, beginning with fundamental concepts and the simplest examples. We then progress to the Transformer architecture, the Vision Transformer, and the landscape of modern Transformer-based pretrained models.

The core idea behind the Transformer model is the attention mechanism, initially conceived as an enhancement for encoder-decoder RNNs in sequence-to-sequence applications, such as machine translation and language models (Bahdanau et al., 2014). The Transformer has become crucial in the current surge of artificial intelligence advancements. We now have smart assistants capable of answering any of our questions, no matter how trivial or incoherent they may seem.

The Transformer architecture can process various types of input data, including audio, language, and images. You are always familiar with OpenAI, ChatGPT. In this module, we will introduce the Vision Transformer, which is essential for self-driving applications. We use Vision Transform in our self-driving RC and show the best performance. It is the foundational model for vision-language models like Open Sora and ChatGPT 4.0.

* Teams start training their third model/check how well their third model work (9:30-11:00 am)
* Lectures by Dantong on Attention Networks (11:00 am - noon)

Lunch Break (12:00pm - 12:30pm)

* Another round of lunch collection (12:30pm- 1pm)
* Giorgian talks about VIT (1:00 pm-1:30 pm)
* Getting ready for Friday (1:30 pm-4:30 pm)
  + Continuously train and improve their self-driving models.
  + Get their models ready for competition
  + Prepare for the presentation on Friday
    - Team name/members
    - your designed route
    - what model used
    - parameters

#### Day 10. Parents' Day, Robotic Racing Competitions (Fast, Furious, and Safe) on-track and off-track, and graduation and certification ceremony

* Test designed route
* Group picture taken
* Complete Survey
* Students do their own Video recording, social media upload
* five-minute presentations from each group.
* 30-minute demo on some R&D topics, such as depth camera, LIDAR (Zeyu Dong)

Lunch Break (12:00pm - 1:00pm)

* Final contest (fast, firm, and furious) (1:00pm-3:30pm)
  + predefined track 1 (15% weight) (1:00-1:30pm)
  + predefined track 2 (15% weight) (1:00-1:30pm)
  + predefined loop in hallway (20% weight) (1:30-2:15pm)
  + design project (50% weight) (2:30-3:30pm)
* Completion Ceremony (3:30pm-4:30pm)
  + Certificates
  + Awards
    - Encouragement
    - Winning Team

Survey Questions

* Who found the camp, you or your parents?
* Website
  + Which site?
* Google Search
  + What keyword?
* Home School

Awards

* Winning Team
  + First
  + Second
  + Third
* Instructor Award - paying attention, doing well on quiz, understanding the theories
  + Michelle & Bethany
  + Kyle & Max
* Youth Award
  + Carter

Video recording review

One-Week Program