

Undergraduate Research: Introducing Deep Learning-based Image Classification to Undergraduate Students

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Abstract

In the past few years, deep learning based methods has quickly become the state of the art in image classification and object detection. As one of the best deep learning structures, Convolutional Neural Network (CNN) is highly automated and requires little prior knowledge. Also, a customized CNN can be quickly built without a large database, if a pre-trained network is provided. These advantages make CNN suitable for undergraduate research. Funded by an 1890 Land Grant Research Project III, CNN is introduced to the undergraduate students in our institution and the students are trained to develop customized CNN in order to solve given image classification problems. The achieved goals and discovered issues are reported and discussed in this work. Overall, the results demonstrated a positive example of integrating modern technology and research into undergraduate classrooms.

1. Introduction

In recent years, the explosion of Artificial intelligence (AI) has made it one of the most intriguing research topics in the world. A recent Forbes report indicated that 80% of enterprises already have some form of AI in production today, and 30% of enterprises are planning on expanding their AI investments over the next 36 months¹. Another recent report from Stanford University² showed that the share of jobs requiring AI skills has grown 4.5 times in the US since 2013. Job openings requiring machine learning and deep learning skills on Monster.com have been more than doubled since 2016. Young people clearly think that AI is a key part of their future, as more and more students choose the subject at university. For example, introductory AI class enrollment at Stanford University has increased 11 times since 1996, in which machine learning course enrollment has been increased from two digits to more than 800². Computer vision engineer and machine learning engineer are the No.3 and No.4 best jobs in the United States in 2018³.

As one of the most successful machine learning models, deep learning have been applied to various fields including computer vision, speech recognition, natural language processing, audio recognition, social network filtering, machine translation, bioinformatics and drug design⁴. Deep learning is an interesting topic in higher education and many talented students in the Science, Technology, Engineering, and Mathematics (STEM) programs are eager for hands-on experience and application that is related to deep learning.

As a HBCU, Central State University is a relatively small institution with a large diverse population of undergraduate students. Funded by an 1890 Land Grant Research Project III in 2017, we are developing deep learning based image classification and object detection systems that can be used in automated plant recognition and weed control. We are looking for undergraduate research assistants in computer science or related majors. The research assistants are expected to carry out research work according to the project schedule, such as developing new image based plant recognition application. However, deep learning was not offered as a course or topic in the classroom in our university before 2017. Thus, a deep learning based term project was designed and added to CPS4420-Software Engineering, a computer science course that is usually open for junior or senior students, but also for sophomores who have sufficient programming background. The objective of this project is to introduce deep learning to undergraduate students with hands-on applications. We are particularly interested in Convolutional Neural Network (CNN), which is a deep learning structure that has been successfully applied to analyzing visual imagery. CNN is designed to require minimal preprocessing, and can be easily customized without a large training database, if a pre-trained network (e.g. AlexNet⁵, GoogLeNet⁶, Inception-v3⁷, MobileNet⁸) is provided. Also, CNN is supported by several well developed software libraries such as TensorFlow, Caffe and PyTorch. These advantages made CNN suitable for undergraduate research that involves students with limited programming skills.

2. Project Design

2.1. Course Setup

CPS4420-Software Engineering is a major required course that offers in fall semester every year. This course teaches students design and implementation issues for software systems, including software life cycle, requirements definition and specification, prototyping, verification, validation, testing, fault-tolerance, social and ethical issues of commercial software, and management.

A term project is assigned to the students after the 2nd interim exam, which is approximately one month before the end of the semester. Each student is requested to design and implement an image classifier using CNN. The students are expected to use transfer learning to customize pre-trained neural networks for new classes. The new network should be able to distinguish at least two new classes that are not included in the pre-trained network. The students are expected to use TensorFlow as the development tool, because it is open source, relatively easy to use, and can be implemented on different platforms. The deliverable of the project is a real-time image classifier that can work as a PC program or an android App.

2.2. Proposal Phase: Since TensorFlow is mostly written in Python, a brief introduction of Python is presented in the classroom, followed by the introduction to deep learning and CNN. The instructor then demonstrates how to install TensorFlow on Windows. Each student is asked to submit a proposal to identify the classes he or she plans to work on. The student also need to justify why the chosen classes are important and a software application should be created to automatically classify them. The proposal is reviewed by a comprehensive face-to-face interview between the instructor and the student. Once the proposal is approved to be feasible, the student can then start to implement the proposed CNN.

2.3. Programming Phase: In this phase, the student needs to build a working CNN based image classifier using TensorFlow. One of the major challenges, as mentioned by Shibberu⁹, is the student's limited programming skill. To address this issue while maintain the student's motivation and self-learning interest, the following reference links are provided for the students to explore.

- Installing Tensorflow on Windows (Windows user), by Tensorflow team¹⁰
- Tensorflow for poets (Linux user), by Google Codelab¹¹
- Build a TensorFlow Image Classifier in 5 Min (Mac user), by Siraj Raval¹²
- Tensorflow-on-raspberry-pi (Raspberry Pi User), by Sam Abrahams¹³

The above references are fairly easy to understand at the undergraduate level. Heavy coding is not required for this project, but the student needs to learn how to collect the database, install TensorFlow and write proper code to retain the network using transfer learning.

2.4. Report Phase: The student needs to prepare a final project report that includes the motivation, the implementation details, the achieved goals and discovered issues, along with a 10-minutes PowerPoint presentation to explain the project to the classmates.

3. Project Assessment

3.1. Assessment Methods

As a small department in a minority institution, we usually only have a small number of students in this course. Five minority students were enrolled in CPS4420 in fall 2017, including four junior students and one senior student. All five students had taken C/C++ programming and/or Java programming courses, however, none of the students had Python programming or machine learning background. The students' learning outcomes were evaluated based on their project reports and presentation. Anonymous questionnaires were collected from all the students to assess the impact of the project. Another face-to-face interview was conducted for each student to discuss the discoveries and issues found in the project.

3.2. Assessment Results

The project assessment results are summarized in Table 1-3.

Student #	Proposed classes	Platform	Network
1	Marijuana / Other plants	Mac OS with Docker	Inception-v3 & MobileNet
2	Music symbols	Mac OS with Docker	Inception-v3 & MobileNet
3	Cats / Dogs	Windows with Anaconda	Inception-v3
4	Weeds / Grass	Windows with Pip	Inception-v3
5	Weeds / Grass	Windows with Pip	Inception-v3

Table 1: Student Project Summary

Total evaluated students	5
Individual Level: Students who agreed that the project progressively deepened and broadened their research skills.	5 (100%)
Course Level: Students who agreed that adding deep learning related projects to the course made it more interesting.	5 (100%)
Program Level: Students who agreed that they were better motivated and engaged to stay in the Computer Science program when modern research topics such as deep learning was offered.	4 (80%)

Table 2: Project Impact Evaluation

Learning Outcome	Assessment Results/Findings	Analysis and Planned Use of Results

1. Understand the basic concept of CNN and justify the practical importance of the proposed classes.	100% students demonstrated adequate understanding of the concept, and proposed original classification tasks that are meaningful in the real world.	The concept of CNN was very attractive to the students. The topic could be properly introduced to students without involving advanced knowledge that might be beyond undergraduate level.
2. Install Tensorflow and necessary dependencies. Test pre-trained neural networks.	Some students struggled when trying to install TensorFlow and make it work on their personal computers. But eventually 100% students were able to install TensorFlow and test pre-trained neural networks successfully.	In-class practice and one-to-one advice helped the students to better understand the work flow. Hands-on practice was considered to be further emphasized.
3. Build a new database with proposed classes, write proper code to fine-tune the architecture of the network, and retrain the network for the new classes.	Two (40%) of the students were able to implement a customized CNN independently. Three (60%) of the students completed a customized CNN with the instructor's assistance.	Coding examples and online references helped the students to handle the implementation issues. Coding background, especially logical thinking, is crucial at this stage.
4. Prepare a final project report and a presentation that explain the motivation, the implementation details, the achieved goals and discovered issues.	100% students showed adequate skill to write a proper project report and prepare a brief presentation to explain the project results and findings.	The students developed more intellectual confidence as they were succeeded in application implementation. A longer project cycle was considered in which students could invest more time to design, validate and modify their code and create more complex projects.

Table 3: Project Learning Outcomes Assessment

3.3. A Project Example

In this project, the student explained his motivation of building an image based Marijuana classifier as follows: The US police investigators use helicopters to spot marijuana growing in rural fields or among other crops¹⁴, while a Marijuana classifier can be installed on a drone and make such process more efficient and cost-effective. The student downloaded 303 Marijuana images and 353 images of other plants from online using an image downloading tool called Fatkun Batch Download Image from Chrome web store (see Figure 1-2).



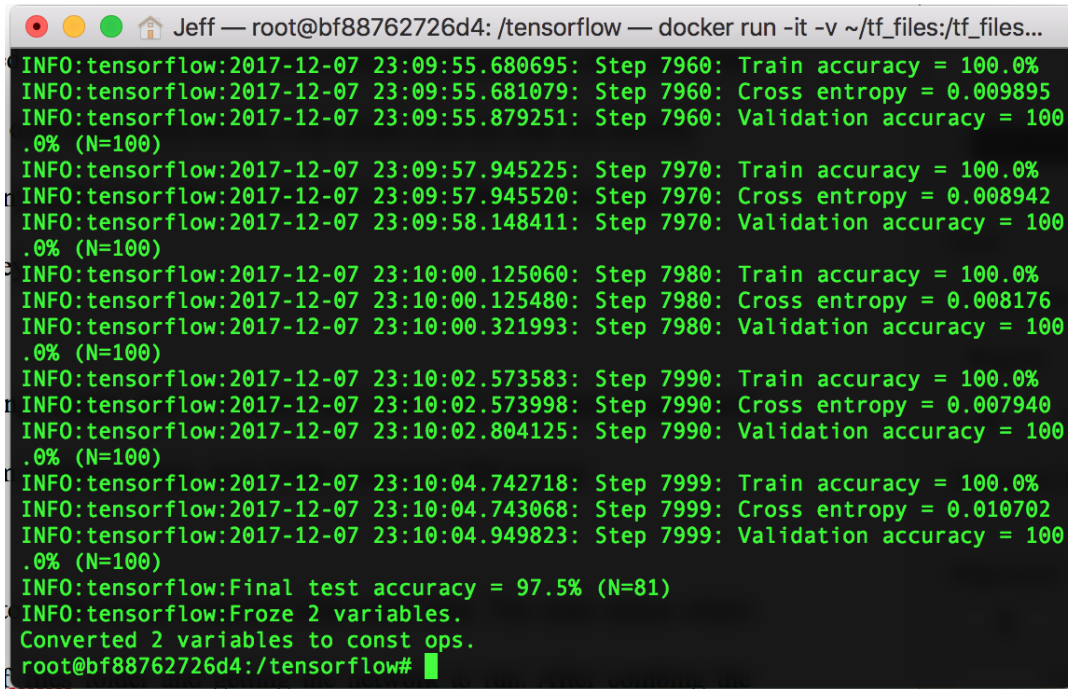
Figure 1: Marijuana image samples



Figure 2: Other plant image samples

The student then tried to install TensorFlow on his own Mac. After a couple of unsuccessful trials, the student was able to installed TensorFlow using Docker. The student fine-tuned

Inception-v3's final layers for the new classes: Marijuana and Other plants. The new classifier showed a 97.5% accuracy on 81 test images (see Figure 3).



```
Jeff — root@bf88762726d4: /tensorflow — docker run -it -v ~/tf_files/tf_files...
INFO:tensorflow:2017-12-07 23:09:55.680695: Step 7960: Train accuracy = 100.0%
INFO:tensorflow:2017-12-07 23:09:55.681079: Step 7960: Cross entropy = 0.009895
INFO:tensorflow:2017-12-07 23:09:55.879251: Step 7960: Validation accuracy = 100.0% (N=100)
INFO:tensorflow:2017-12-07 23:09:57.945225: Step 7970: Train accuracy = 100.0%
INFO:tensorflow:2017-12-07 23:09:57.945520: Step 7970: Cross entropy = 0.008942
INFO:tensorflow:2017-12-07 23:09:58.148411: Step 7970: Validation accuracy = 100.0% (N=100)
INFO:tensorflow:2017-12-07 23:10:00.125060: Step 7980: Train accuracy = 100.0%
INFO:tensorflow:2017-12-07 23:10:00.125480: Step 7980: Cross entropy = 0.008176
INFO:tensorflow:2017-12-07 23:10:00.321993: Step 7980: Validation accuracy = 100.0% (N=100)
INFO:tensorflow:2017-12-07 23:10:02.573583: Step 7990: Train accuracy = 100.0%
INFO:tensorflow:2017-12-07 23:10:02.573998: Step 7990: Cross entropy = 0.007940
INFO:tensorflow:2017-12-07 23:10:02.804125: Step 7990: Validation accuracy = 100.0% (N=100)
INFO:tensorflow:2017-12-07 23:10:04.742718: Step 7999: Train accuracy = 100.0%
INFO:tensorflow:2017-12-07 23:10:04.743068: Step 7999: Cross entropy = 0.010702
INFO:tensorflow:2017-12-07 23:10:04.949823: Step 7999: Validation accuracy = 100.0% (N=100)
INFO:tensorflow:Final test accuracy = 97.5% (N=81)
INFO:tensorflow:Froze 2 variables.
Converted 2 variables to const ops.
root@bf88762726d4: /tensorflow#
```

Figure 3: A retrained CNN classifier that can distinguish Marijuana from Other plants with 97.5% accuracy.

4. Conclusion

Although not statistically conclusive, the assessment results suggested that the hands-on deep learning related project is an intriguing experience for undergraduate students and it could benefit a diverse population of students by motivating, engaging, and enhancing their learning and understanding. The results demonstrated a positive example of integrating modern technology and research into undergraduate education.

From undergraduate research perspective, the project exposed participating undergraduate students to the possibilities of graduate study and encouraged them to choose a career path involving research. We observed that the students developed more intellectual confidence as they were succeeded in hands-on experiences and application implementation. They benefited greatly when collaborating with other students who share their commitment to science, mathematics, and engineering. The project also advanced the research skills of the undergraduate students and enhanced the research and employment opportunities for these students. Shortly after joined this project, one student was offered an on-campus research

assistantship by the 1890 Land Grant Research Project III. And another student was invited to a NASA summer student research fellowship.

References:

1. Columbus L. 80% Of Enterprises Are Investing In AI Today, 2017.
<https://www.forbes.com/sites/louiscolumbus/2017/10/16/80-of-enterprises-are-investing-in-ai-today/>
2. Artificial intelligence Index Annual Report, 2017.
<http://cdn.aiindex.org/2017-report.pdf>
3. The Best Jobs in the United States: 2018, Indeed blog, 2018.
<http://blog.indeed.com/2018/03/15/best-jobs-united-states/>
4. F Ghasemi, AR Mehridehnavi, A Fassihi, H Perez-Sanchez. Deep Neural Network in Biological Activity Prediction using Deep Belief Network, Applied Soft Computing, 2017.
5. A Krizhevsky, I Sutskever, GE Hinton. ImageNet Classification with Deep Convolutional Neural Networks, Advances in neural information processing systems, 2012.
6. C Szegedy, W Liu, Y Jia, P Sermanet, S Reed, D Anguelov, D Erhan, V Vanhoucke, A Rabinovich. Going Deeper with Convolutions, Computer Vision and Pattern Recognition, 2015.
7. C Szegedy, V Vanhoucke, S Ioffe, J Shlens, Z Wojna. Rethinking the Inception Architecture for Computer Vision, Computer Vision and Pattern Recognition, 2015.
8. A G. Howard, M Zhu, B Chen, D Kalenichenko, W Wang, T Weyand, M Andreetto, H Adam. MobileNets: Efficient Convolutional Neural Networks for Mobile Vision Applications, Computer Vision and Pattern Recognition, 2017.
9. Y Shibberu. Introduction to Deep Learning: A First Course in Machine Learning, ASEE Annual Conference & Exposition, Columbus, Ohio, 2017.
<https://peer.asee.org/28582>
10. TensorFlow Team, Installing Tensorflow on Windows.
https://www.tensorflow.org/install/install_windows
11. Google Codelab, Tensorflow for poets.
<https://codelabs.developers.google.com/codelabs/tensorflow-for-poets>
12. S Raval. Build a TensorFlow Image Classifier in 5 Min.
https://github.com/II-Sourcell/tensorflow_image_classifier
13. S Abrahams. Tensorflow-on-raspberry-pi.
<https://github.com/samjabrahams/tensorflow-on-raspberry-pi>
14. E Masters. Troopers fly Bell helicopter to find pot in the fields. Timesunion, 2016.
<http://www.timesunion.com/tuplus-local/article/Troopers-fly-Bell-helicopter-to-find-pot-in-the-9706923.php>