SACRED HEART SCHOOLS
PREPARATORY

SENIOR HONORS INDEPENDENT STUDY APPLICATION

Name of Student Applicant: Antonio Caceres

I. COURSE DESCRIPTION

Name of project: Imitating Intelligence: An Investigation into the Implementation and Applications of Neural Networks
Department sponsoring project: Computer Science
Name of on-campus mentor: Mr. Michael Vaganov
Names and professional credentials of three (3) off-campus mentors, including their title and occupations and a phone number or email address where they can be reached.

- Dr. Abdelrahman Mohamed (abdemoh@amazon.com): PhD in Deep Learning; scientist at Amazon and specializes in Machine Learning for Amazon Echo
- Dr. Thorsten Joachims (tj@cs.cornell.edu): Computer Science professor and Head of Computer Science at Cornell University; Publication on Neural Nets using Bandit Feedback
- Dr. William Wang (william@cs.ucsb.edu): PhD from Carnegie Mellon, CS Assistant Professor at USCB, Publications on Recurrent Neural Nets, Researcher in Machine Learning
- Mrs. Sudha Sundaresan (sunsudha@amazon.com): Software/Programming Expert, Experience in Cloud Engineering, Engineering Leader at Amazon Alexa

Description of Experience of Independent Work

In my classes, I like to teach myself new content ahead of the class material; the most relevant example to my Independent Study was in Mr. Morris's AP Computer Science class. During one lesson, he had the class download some code online to support a picture program we were writing. We weren't taught what the downloaded code did since it was more advanced, but the professor who had written the program had added comments explaining the code. I read the comments, did some online research, and experimented with the code to begin to understand how the back-end code worked. Meanwhile, the class had run into a bug where shrinking an image would cause duplicate images to appear. The class never fixed it because it was a problem with the supporting code, but that night I used the concepts from the code I had read to edit that supporting code and fix the bug. Although this project is only a small example of independent work, I think it demonstrates my ability to learn from experimentation and research which will be extremely useful during my SHIS project.

Guiding/Essential Questions

- How do neural networks work, and what determines the functions applied in the nodes?
- What are the different types of neural networks and where do they work best?
    - What is the difference between feedforward and feedback/recurrent neural networks?
- What are some potential applications of neural networks?
- What kinds of mental labor are humans better at than artificial neural networks?

Description of Content Areas

For my Independent Study, I will be researching neural networks, a layered system of nodes in computer science designed to imitate the processes of biological brains. Each node receives inputs, either from weighted nodes in previous layers, from inputs given to the network, and mathematical functions applied to the inputs. During monitored training, the neural network is given the correct output, and compares its output with the correct one. If they don't match, the network adjusts its weights by a small amount and repeats the process.

During my Independent Study, I want to deepen my understanding of the processes and mathematics that occur in a neural network. In addition, I will investigate and compare the types of neural networks, such as feedforward versus feedback ones or single-layer versus multilayer ones. There are also a handful of other topics I know nothing about, such as bias nodes, but intend to explore. I have decided to learn about neural networks through my Senior Honors Independent study because they are so complicated, mathematically and through their implementation. Thus, it will take me a long time to begin to understand the concept.

Description of your motivation for pursuing this independent study

Throughout high school and all of the computer science courses I have taken, I have always had a passion for programming and wanted to do an Independent Study in computer science. I started coding in CS1 during freshman year, learned elementary Java and C++ with Mr. Vaganov as an extracurricular, and took AP Computer Science my junior year. I am registered to take Advanced Topics in Computer Science and Building Virtual Worlds next year if enough students register for those courses. However, neural networks are quite new to the field of computer science, more complicated than most content in those courses, and not covered extensively in my courses next year, so I want to do an Independent Study investigating them.

To prepare myself over the summer, I will be programming a lot to familiarize myself with the languages I know, learning Python, and reading some introductory books on neural networks. During the semester, I will take some online courses, do additional research with one or two more books and some online publications, and design my own simple neural network. Overall, I think this Senior Honors Independent Study is an opportunity to learn about this modern topic in programming and prepare for undergraduate computer science research in college.

List of Objectives and Learning Goals

By the end of my independent study, I intend to:

- understand the processes and math that make an artificial neural network function.
- understand the different types of neural networks and their applications.
- investigate when a human is more effective than an artificial neural network, and vice versa.
- build my own simple neural network to learn a task like recognizing patterns or playing a game.

List and Description of Key Assignments and Major Assessments

- **Small Presentation with a Simple Explanation of Neural Networks**
    - Diagram Describing how a Neural Network Recognizes Something

- **Train a Neural Network** to Tell the Difference Between Three or Four Different Objects
- **Outline** a 'Learning Path' for another Student to Learn about Neural Networks
- **Program** a Backpropagating Neural Network so the Computer 'Imagines' an Object

Formal Bibliography of Proposed Resources

Works Cited

Abu-Mostafa, Yaser S, et al. *Learning From Data*. AMLBook, 2012.

Badar, Altaf, et al. "Study of Artificial Intelligence Optimization Techniques applied to Active Power Loss Minimization." *IOSR Journal of Electrical and Electronics Engineering*, edited by Aetes Haroeri, International Conference on Advances in Engineering & Technology, vol. 2, International Organization of Scientific Research, 2014, pp. 39-45.

Downing, Keith L. *Intelligence Emerging: Adaptivity and Search in Evolving Neural Systems*. MIT Press, May 2015.

Fausett, Laurene V. *Fundamentals of Neural Networks: Architectures, Algorithms And Applications*. 1st ed., Pearson, 19 Dec. 1993.

Glorot, Xavier, and Yoshua Bengio. "Understanding the Difficulty of Training Deep Feedforward Neural Networks." U of Montréal, 2010.

Heaton, Jeff. *Introduction to Neural Networks with Java*. 2nd ed., Heaton Research, 1 Oct. 2008.

Howard, Jeremy and Rachel Thomas. "Practical Deep Learning for Coders". *Fast.ai*, 2018, course.fast.ai.

Joachims, Thorsten, et al. *Deep Learning with Logged Bandit Feedback*. International Conference on Learning Representations (ICLR), 2018. www.cs.cornell.edu/people/tj/publications/joachims_etal_18a.pdf.

Krose, Ben, and Patrick Smagt. "An Introduction to Neural Networks." 8th ed., U of Amsterdam, Nov. 1996.

Ripley, Brian D. “Neural Networks and Related Methods for Classification.” *Journal of the Royal Statistical Society Series B*, edited by D. Dunson and S. Wood, vol. 56, no. 3, 1994, pp. 409-456.

Schmidhuber, Jürgen. “Deep Learning in Neural Networks: An Overview.” *Neural Networks*, edited by Kenji Doya and DeLiang Wang, vol. 61, Jan. 2015, pp. 85-117. arxiv.org/pdf/1404.7828v4.pdf.

Nielsen, Michael. *Neural Networks and Deep Learning*. Determination Press, 2015.

“Neural Networks.” *World of Computer Science*, Gale, 2007. Science In Context.

II. DETAILED 16 WEEK SYLLABUS

Summer Work:

June: 6/17 - 6/23, 6/24 - 6/30

- Course: Udemy course on Python 3 – Milestone Project #2
    - This is an introductory course covering beginner to intermediate Python.

July: 7-22 - 7/28

- Course: Udemy course on Python – Begin Final Capstone Project
- Reading: *Introduction… with Java* – Overview of Neural Networks (22 pg.)
- Reading: *An Introduction to Neural Networks* – Fundamentals (10 pg.)

August: 8/5 - 8/11

- Course: Udemy course on Python – Finish Capstone Project
- Reading: *Introduction… with Java* – Matrix Operations (22 pg.)
- Other: Learn about Amazon SageMaker with help from Dr. Mohammed if needed.
    - Amazon SageMaker is a machine-learning development platform developed by AWS.

Semester Work:

Week One: First Stage of Study – Learning the Fundamentals of Neural Networks

- Course: Fast.ai Course on Neural Networks – Week 1/7
    - This is a seven-week introductory course on neural networks and machine learning.
- Reading: *Introduction… with Java* – Using a Hopfield Neural Network (36 pg.)
- Reading: "Neural Networks" from Gale Science in Context
- Assignment: Begin small presentation to explain what I've learned as simply as I can.

Week Two

- Course: Fast.ai Course on Neural Networks – Week 2/7
- Reading: *Neural Networks and Deep Learning* – Introduction and Chapter One
- Reading: Begin *An Introduction to Neural Networks* – Theory (~20/62 pg.)
- Assignment: Create small presentation and diagram simply explaining what I've learned.

Week Three

- Course: Fast.ai Course on Neural Networks – Week 3/7
- Reading: Continue *An Introduction to Neural Networks* – Theory (~20/62 pg.)
- Reading: *Introduction… with Java* – How a Machine Learns (24 pg.)
- Assignment: Small presentation and diagram. Show progress to Advisor for initial feedback.
- Assignment: Create a feedback form for my small presentation.

Week Four

- Course: Fast.ai Course on Neural Networks – Week 4/7
- Reading: Finish *An Introduction to Neural Networks* – Theory (~22/62 pg.)
- Reading: "Deep Learning in Neural Networks: An Overview" – Intro to Deep Learning (4 pg.)
- Reading: *Neural Networks and Deep Learning* – Chapter 2
- Assignment: Finish the small presentation and diagram.
- Assignment: Give the small presentation to colleagues for feedback to revise it.

Week Five

- Course: Fast.ai Course on Neural Networks – Week 5/7
- Reading: Begin *Introduction… with Java* – Feedforward Neural Networks (~15/30 pg.)
- Reading: *Neural Networks and Deep Learning* – Chapter 3
- Assignment: Program a neural network with Python that recognizes 2 or 3 different objects.
- Submission: Present the small presentation to Mr. Vaganov (on-campus mentor) for grading.

Week Six

- Course: Fast.ai Course on Neural Networks – Week 6/7
- Reading: Finish *Introduction… with Java* – Feedforward Neural Networks (~15/30 pg.)
- Reading: "An Introduction to Neural Networks" – Applications (24 pg.)
- Assignment: Program a neural network with Python that recognizes 2 or 3 different objects.

Week Seven

- Course: Fast.ai Course on Neural Networks – Week 7/7
- Assignment: Program a neural network with Python that recognizes 2 or 3 different objects.
- Other: Finish any work that has been pushed back due to scheduling.

Week Eight: Second Stage of Study – Complicating the Topic

- Reading: *Intelligence Emerging* – Introduction (20 pg.)
- Reading: *Fundamentals of Neural Networks* – Introduction (38 pg.)
- Assignment: Design a "learning path" to introduce a CS student to Neural Networks
- Assignment: Program a neural network with Python that recognizes 2 or 3 different objects.
- Presentation: Start outlining the final presentation of my Independent Study.

Week Nine

- Reading: *Intelligence Emerging* – Emergence (21 pg.)
- Reading: Begin *Fundamentals…* – Simple Neural Nets for Pattern Classification (~30/62 pg.)
- Assignment: Program a neural network with Python that recognizes 2 or 3 different objects.
- Assignment: Design a "learning path" to introduce a CS student to Neural Networks

Week Ten

- Reading: *Intelligence Emerging* – Search: The Core of AI (24 pg.)
- Reading: *Fundamentals…* – Simple Neural Nets for Pattern Classification (~20/62 pg.)
- Assignment: Design a "learning path" to introduce a CS student to Neural Networks
- Presentation: Start to put together my final presentation.
- Submission: Demonstrate the visual recognition neural network for grading.

Week Eleven

- Reading: *Intelligence Emerging* – Artificial Neural Networks (30 pg.)
- Reading: *Fundamentals…* – Simple Neural Nets for Pattern Classification (~12/62 pg.)
- Reading: "Deep Learning in Neural Networks: An Overview" – Supervised NNs, Some Helped by Unsupervised NNs (21 pg.)

- Assignment: Add backpropagation to the visual recognition neural network, emailing off-campus mentors as necessary.
- Presentation: Continue to put together my final presentation and list the content I'm missing.
- Submission: Present the introductory "learning path" for Neural Networks to Mr. Vaganov.
- Other: Finish any work that has been pushed back due to scheduling.

Week Twelve: Third Stage of Study – Rounding it Out

- Reading: *Fundamentals…* – Pattern Association (~25/55 pg.)
- Reading: *Fundamentals…* – Backpropagation Neural Net (45 pg.)
- Presentation: Continue to put together my final presentation and list the content I'm missing.
- Assignment: Add backpropagation to the visual recognition neural network.

Week Thirteen

- Reading: *Fundamentals…* – Pattern Association (~30/55 pg.)
- Reading: "Understanding the Difficulty of Training Deep Feedforward Neural Networks" (8 pg.)
- Reading: *Intelligence Emerging* – Knowledge Representation in Neural Networks (34 pg.)
- Presentation: Continue to put together my final presentation and find sources for content.
- Assignment: Add backpropagation to the visual recognition neural network.

Week Fourteen

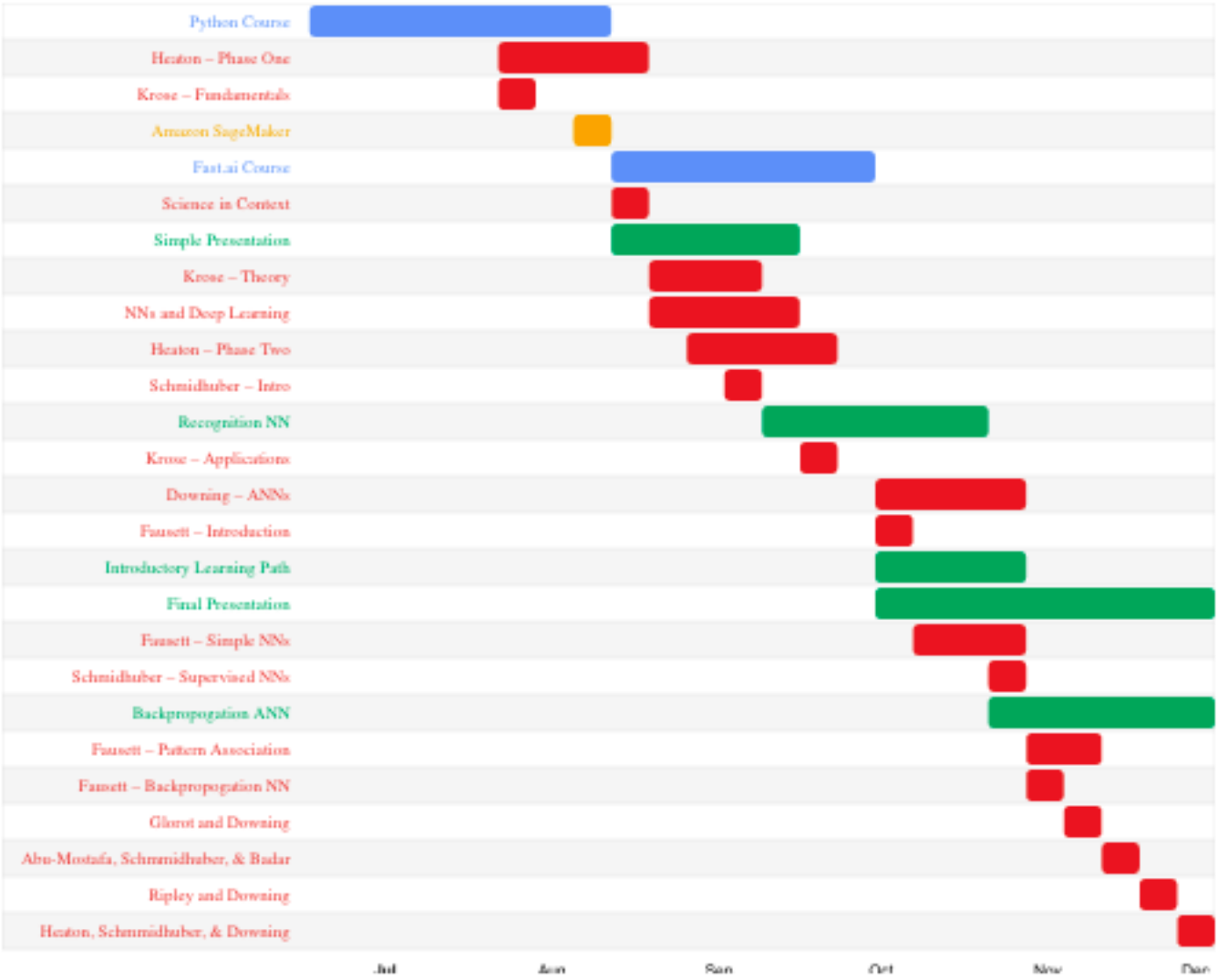
- Reading: *Learning From Data* – The Learning Problem (38 pg.)
- Reading: "Deep Learning in Neural Networks: An Overview" – DL in FNNs and RNNs for Reinforcement Learning (RL) (5 pg.)
- Reading: "Study of Artificial Intelligence Optimization Techniques" (7 pg.)
- Presentation: Continue to put together my final presentation and find sources for content.
- Assignment: Add backpropagation to the visual recognition neural network.

Week Fifteen

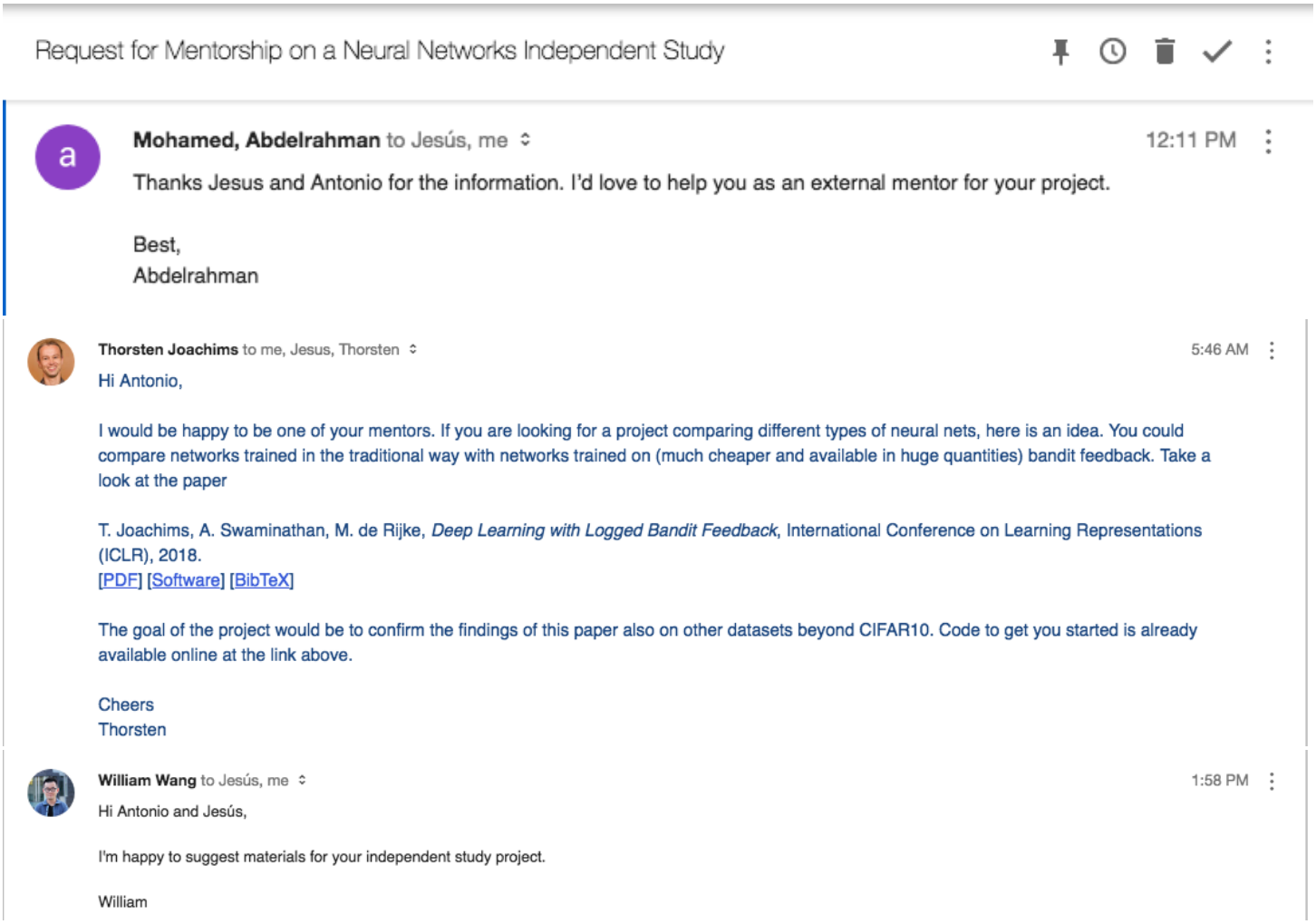
- Reading: "Neural Networks and Related Methods for Classification" (48 pg.)
- Reading: *Intelligence Emerging* – Evolving Artificial Neural Networks (~20/52 pg.)
- Presentation: Finish a draft of my final presentation and begin practicing.
- Assignment: Add backpropagation to the visual recognition neural network.
- Other: Read any other sources necessary for my final presentation.
- Other: Finish any work that has been pushed back due to scheduling.

Week Sixteen

- Reading: *Introduction… with Java* – The Future of Neural Networks (10 pg.)
- Reading: "Deep Learning in Neural Networks: An Overview" – Conclusion and Outlook (1 pg.)
- Reading: *Intelligence Emerging* – Evolving Artificial Neural Networks (~32/52 pg.)
- Reading: *Intelligence Emerging* – Neural Network Sidelights (16 pg.)
- Finish the final neural network and my final presentation.


Python Course
Heaton – Phase One
Krose – Fundamentals
Amazon SageMaker
Fast.ai Course
Science in Context
Simple Presentation
Krose – Theory
NNs and Deep Learning
Heaton – Phase Two
Schmidhuber – Intro
Recognition NN
Krose – Applications
Downing – ANNs
Fausett – Introduction
Introductory Learning Path
Final Presentation
Fausett – Simple NNs
Schmidhuber – Supervised NNs
Backpropogation ANN
Fausett – Pattern Association
Fausett – Backpropogation NN
Glorot and Downing
Abu-Mostafa, Schmmidhuber, & Badar
Ripley and Downing
Heaton, Schmmidhuber, & Downing

III. EMAILS OF AGREEMENT FROM THREE OFF-CAMPUS MENTORS



Request for Mentorship on a Neural Networks Independent Study

Mohamed, Abdelrahman to Jesús, me 12:11 PM

Thanks Jesus and Antonio for the information. I'd love to help you as an external mentor for your project.

Best,
Abdelrahman

Thorsten Joachims to me, Jesus, Thorsten 5:46 AM

Hi Antonio,

I would be happy to be one of your mentors. If you are looking for a project comparing different types of neural nets, here is an idea. You could compare networks trained in the traditional way with networks trained on (much cheaper and available in huge quantities) bandit feedback. Take a look at the paper

T. Joachims, A. Swaminathan, M. de Rijke, *Deep Learning with Logged Bandit Feedback*, International Conference on Learning Representations (ICLR), 2018.
[PDF] [Software] [BibTeX]

The goal of the project would be to confirm the findings of this paper also on other datasets beyond CIFAR10. Code to get you started is already available online at the link above.

Cheers
Thorsten

William Wang to Jesús, me 1:58 PM

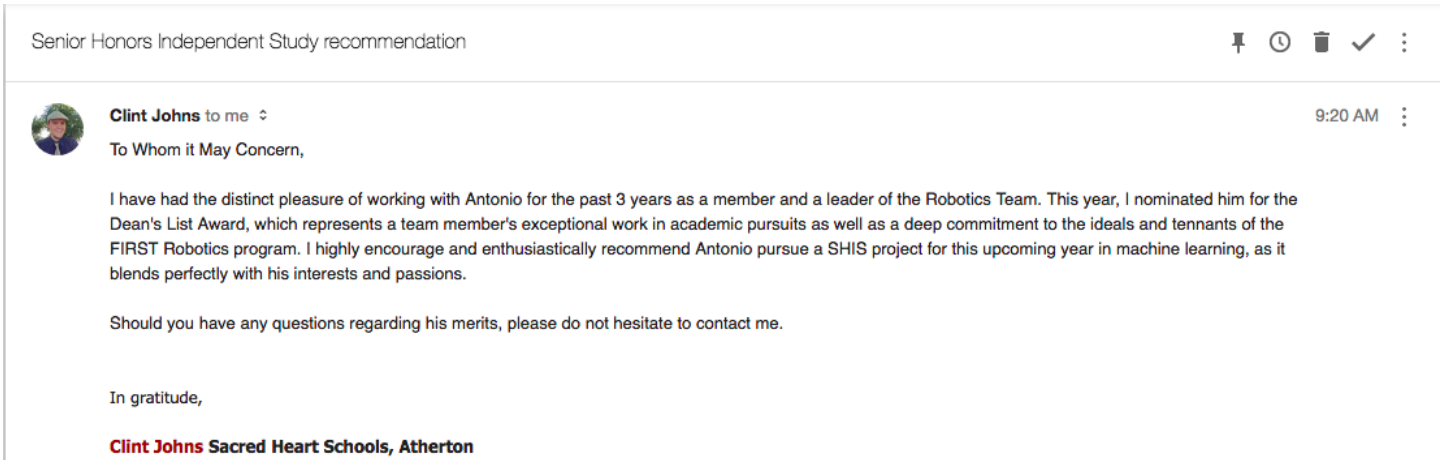
Hi Antonio and Jesús,

I'm happy to suggest materials for your independent study project.

William

IV. EMAIL OF RECOMMENDATION FROM A SACRED HEART TEACHER

verifying your ability to undertake and follow through on independent work of a sustained nature.



Senior Honors Independent Study recommendation

Clint Johns to me 9:20 AM

To Whom it May Concern,

I have had the distinct pleasure of working with Antonio for the past 3 years as a member and a leader of the Robotics Team. This year, I nominated him for the Dean's List Award, which represents a team member's exceptional work in academic pursuits as well as a deep commitment to the ideals and tennants of the FIRST Robotics program. I highly encourage and enthusiastically recommend Antonio pursue a SHIS project for this upcoming year in machine learning, as it blends perfectly with his interests and passions.

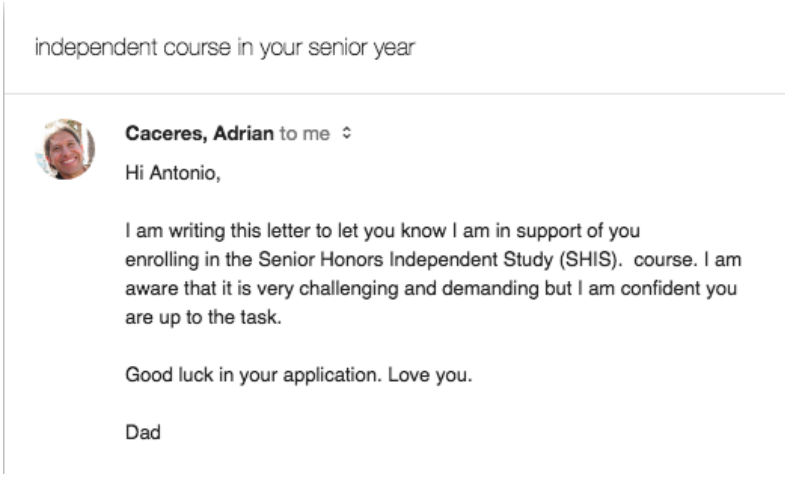
Should you have any questions regarding his merits, please do not hesitate to contact me.

In gratitude,

Clint Johns Sacred Heart Schools, Atherton

V. EMAIL FROM PARENT/GUARDIAN

indicating an understanding of the I.S. program, its rigor and assessment guidelines, and support of the student's application.



independent course in your senior year

Caceres, Adrian to me

Hi Antonio,

I am writing this letter to let you know I am in support of you enrolling in the Senior Honors Independent Study (SHIS). course. I am aware that it is very challenging and demanding but I am confident you are up to the task.

Good luck in your application. Love you.

Dad

VI. BRIEF STATEMENT OF PREFERENCE FOR FALL/SPRING SEMESTER

I would prefer to do the project during the fall semester. During spring, robotics building and competitions takes nearly all of my time during the first two months of the year. In addition, since I'm playing Varsity tennis this year, I will likely be playing Varsity next year as well, thus much of my time after school will be dedicated to matches. During fall, I have almost no commitments outside of school and college applications. Finally, it is much more likely for me to have open courses in the fall semester.