Ultrafast Artificial-Neural-Network Vision Sensor

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SHINE – Summer High School Intensive in Next-Generation Engineering

Introduction

The invention of machine learning algorithms, especially Artificial Neural Networks (ANN), had massive impacts on machine vision technology and various intelligent system associated with it, including autonomous vehicles and robotics. However, training an ANN requires a high volume of data with a long period of time, and during the process, large amounts of redundant data being passed through the entire signal chain result in the processed image at low frame rates and cost high-power consumption. In Professor Kapadia's research lab, our team is trying to design a power-efficient ultrafast image sensor by using arrays of 2-D photodetector devices with attached amplifiers. With Professor Kapadia and my Ph.D. Mentors Jun Tao & Ragib Ahsan, I used a programmed package simulator called Cross-Sim to simulate the data model by taking sets of photoresponsivity data and then evaluated the performance of ANN photodiode arrays by analyzing resulted data trends.

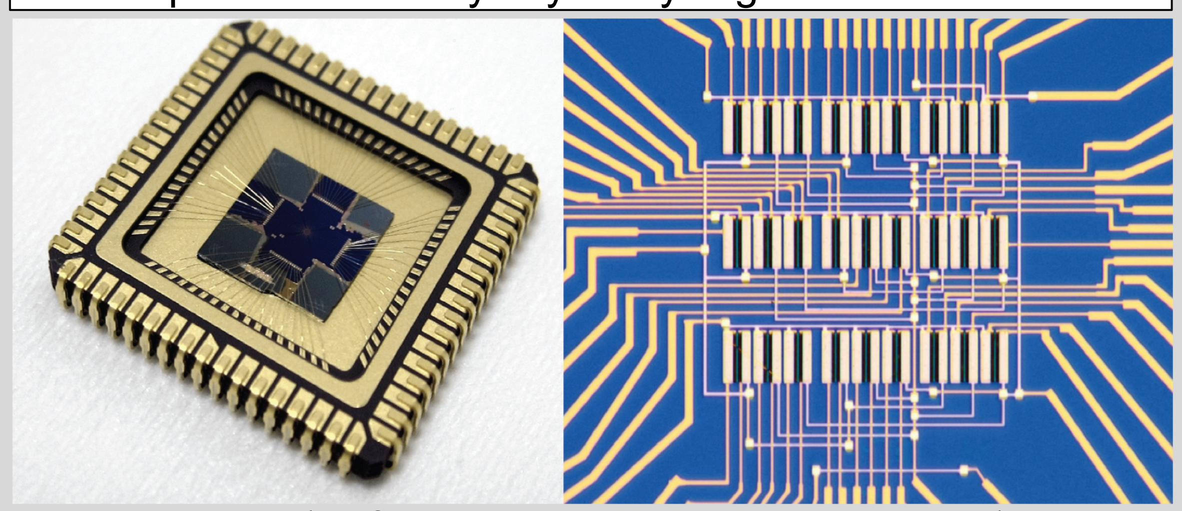

Fig 1. Ultrafast image sensor. PC: Nature Journal

Objective & Impact of Professor's Research

Professor Kapadia's research objective is to use alternative materials and electronic devices to create new concepts and approaches for future computing systems. To create the power-efficient ultrafast image sensor, we are aiming to have programmable photocurrents from photodetectors by implementing the amplifiers. By doing this, we can store the weight in the array, and directly use measured current to do image recognition. This approach doesn't require the analog to digital conversion of original image, hence it's faster than the traditional deep learning approach, which can achieve a faster rate of data processing and image recognition by accelerating AI computational speed within neural networks, while power-efficiency is also improved in the computing devices. The outcome will open the door for next-generation AI and machine learning in computer chip manufacturing industries as well as other new technological advancement devices such as other ultrafast image recognition technologies and faster machine learning algorithms. Boosting up computing speed will allow researchers to find a better solution to implement this technique to make AI more convenient and easily accessible to people in the future.

Research & Learning Process

Because our research is mainly conceptual and theoretical, I first started to learn about basic concepts of semiconductors, neural networks, and deep learning.

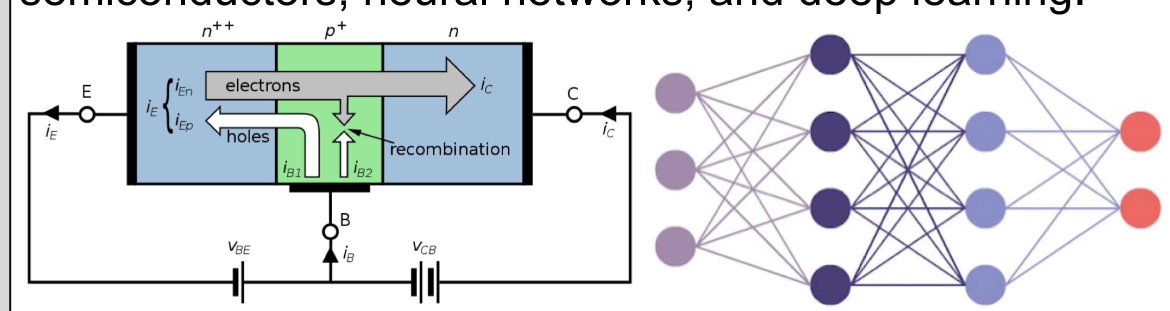

Fig 2. Bipolar junction transistor & neural networks. PC: Darwin Zhang

Then, I worked on a project that more focuses on the functionalities of analog photodetection devices, by using Arduino devices (Arduino Mega 2560 & photoresistor) and programming languages (Python, C/C++)

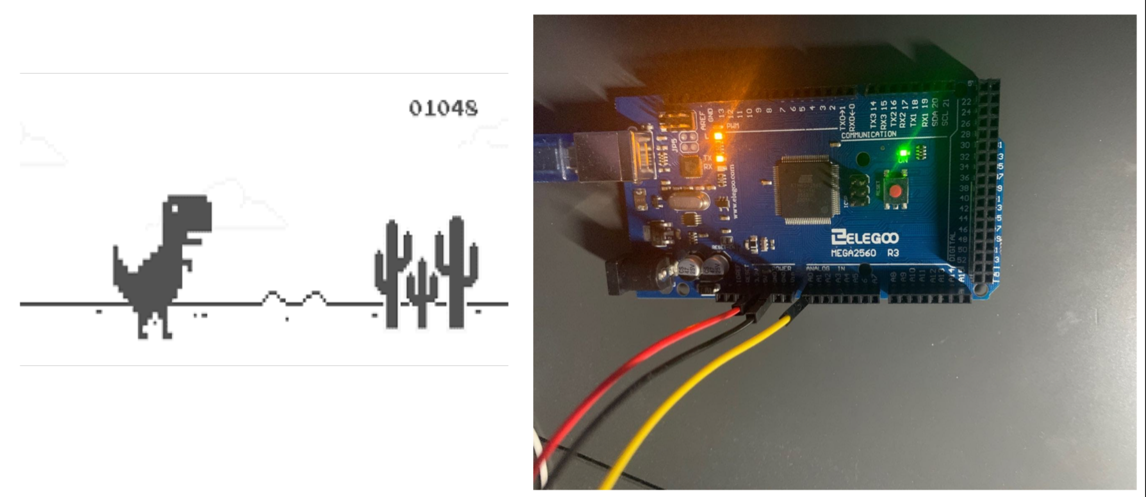

Fig 3. Automated dinosaur jumping game. PC: Darwin Zhang

After the hands-on learning, I started to explore further in our research project, in which I learned about a cross-bar simulation tool called Cross-Sim (written in Python). By using this programming package, I started to help my mentors to use their measured data to perform data modelling for our main project, the ultrafast image sensor.

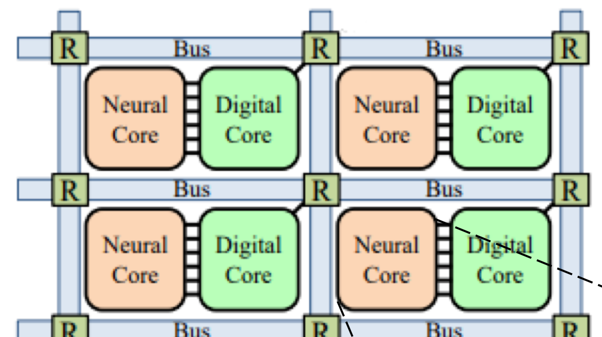

Fig 4. Neural Architecture PC: Cross-Sim

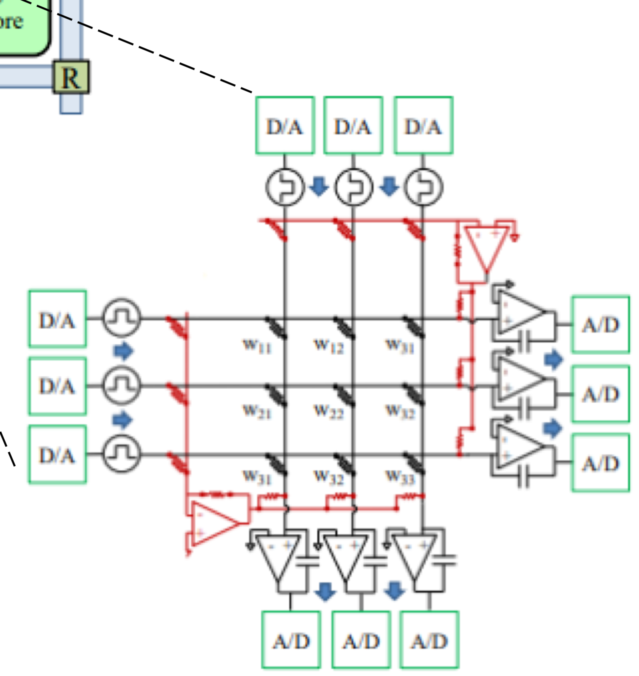

Fig 5. A neural Core PC: Cross-Sim

Methods & Results

By using the crossbar simulator, I have modeled sets of data that represent weights being stored into photoresponsivity.

1. The predetermined data sets - photoresponsivity - were initially changed by modifying amplification, in other words, we assumed noise were applied into the image, so that way we could maximize the accuracy of the ultrafast image sensor model realistically.
2. By using data files (.csv) with Cross-Sim, we generated an experimental lookup table model, which takes an experimentally measured ΔG vs G (conductance) plot and uses that to compute the noise updates.

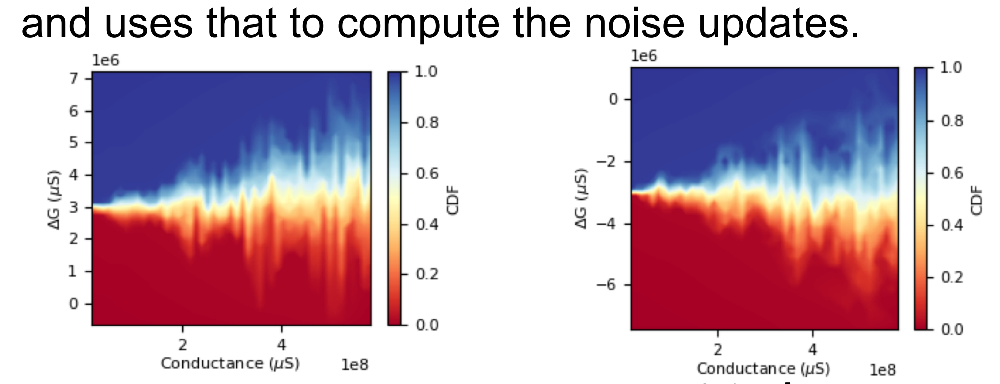

Fig 6 & 7. Heat map representation of the ΔG versus G

3. While the noise is updating, the lookup table also derives itself into two separate output files for increasing and decreasing in terms of conductance and cumulative distribution function (CDF), which will be take into neural network training.
4. The conductance vs. CDF data will then be trained by using three types of datasets:
   - **Small Image**: an 8x8 version of MNIST
   - **Large Image**: 28x28 MNIST handwritten digits dataset
   - **Cyber File Types**: 256 byte-pair statistical attributes to classify 9 file types

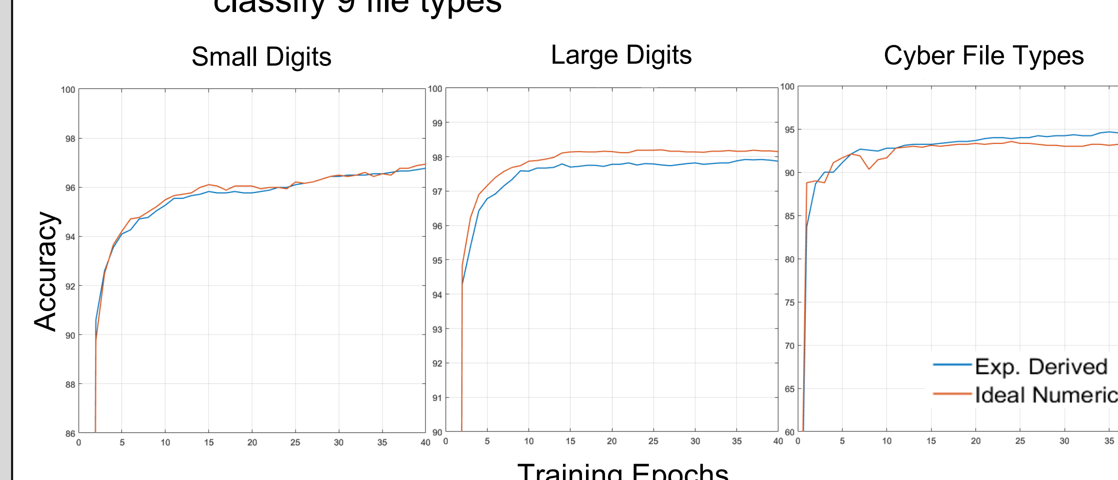

Fig 8. Small image accuracy *Fig 9. Large image accuracy* *Fig 10. Cyber file accuracy*

According to Fig. 8-10, we could see a trend that all three data simulations are achieving high efficiencies in image recognition. Additionally, the linear data has much greater accuracy than the nonlinear data in which the noise-applied data in the cyber file is having greater accuracy than ideal data, and the noise-applied data in the small image also had reached beyond the ideal data. As a result, our proposed ultrafast vision sensor is highly applicable in next-generation AI technologies and other related image sensing devices, which can greatly accelerate computational speed while also improving power efficiency. *(Fig 6-10 PC: Darwin Zhang)*

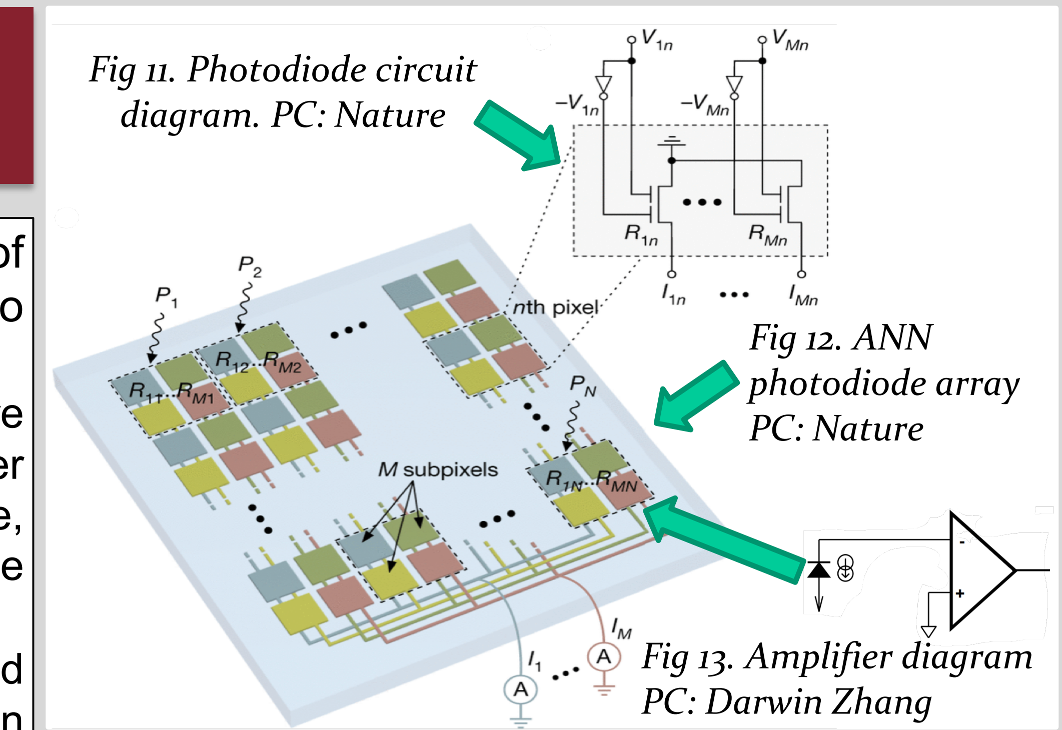

Fig 11. Photodiode circuit diagram. PC: Nature

Fig 12. ANN photodiode array PC: Nature

Fig 13. Amplifier diagram PC: Darwin Zhang

Next Steps

Since our simulation is theoretically validated, the next step would be the fabrication of the device (Fig.1). Throughout these 7 weeks, I have effectively furthered my interests in the electrical and computer engineering field of study by understanding many fundamental concepts in AI computation and semiconductor devices. By continuously developing my skills in data simulation and programming, I would like to keep working on this current or other related projects with my mentors. I believe my unique experiences at SHINE will keep leading me to explore more STEM knowledge in the future.

Advice for Future SHINE Students

- Learn as much as you can, prepare for bigger tasks as research is going deeper.
- Be flexible and creative, because problems might come up at some point.
- Don't hesitate to ask for help from people around you, this is a strong community.
- Stay connected with your PI/Ph.D. Mentor.
- Be nice, be respectful, be motivated :)

Acknowledgements

I would like to thank Dr. Mills, Cathalina Juarez, and all SHINE staffs for organizing this amazing experience for us, my professor, Dr. Kapadia, for including me in his research group, my mentors, Jun Tao and Ragib Ahsan, for teaching us about this project and providing us their guidance with support throughout my time here, and Tyler Weigand for working with me to work on this research project and being a great lab partner.