UCTS Program Attendance Report

Da-Wei Chang (張大衛)

Background

The UChicago-Taiwan Student Exchange (UCTS) exchange program, organized by Professor Chen Chin, provides a chance to perform summer research at the University of Chicago (UChicago). The program includes 29 Taiwanese students from National Taiwan University (NTU), National Tsing Hua University (NTHU), and National Cheng Kung University (NCKU). Funded by UCTS programs from UChicago and the Office of International Affairs (OIA) in NTU, the UCTS fellows from NTU are fully supported with the full cost of tuition, fees, and housing.

UCTS first meet in UChicago

UCTS 2025 took place from June 16 to August 29. During the program, I worked with Professor Chein-Min Kao and Professor Chin-Tu Chen for medical image reconstruction using AI or neural networks. I lived in the campus dorm (Campus North Residential Commons) with other UCTS fellows. I worked with my PIs on weekdays and had free time to travel around on weekends. It provides a good chance to progress my research career in a world-famous university and explore different cultures in a foreign city.

Research Project at UChicago

<u>Introduction and Motivation</u>

My research topic at the University of Chicago is “Exploration of Low-Count Dual-Panel TOF-PET Image Reconstruction Using Neural Network.” This research explores potential image reconstruction techniques for a specialized mobile Positron Emission Tomography (PET) system designed for pretreatment during the Transarterial Radioembolization (TARE) procedure. PET pretreatment imaging aims to ensure the correct placement of the catheter, which is crucial for killing the cancer cells while preventing harm to the normal liver cells.

This specialized PET system would cause a low count in the observed data and changes in detector shapes. To prevent harming the patient in case the placement of the catheter is wrong, only a small amount of tracer could be injected during the pretreatment imaging. Such a restriction causes the amount of observed data to become lower, directly increasing the difficulty of image reconstruction. On the other hand, since a formal treatment procedure should follow the pretreatment, the patient could not be moved to another operating room for the imaging. Due to such a limitation, a smaller and mobile design of the PET detectors is desired. Compared with the usual cylinder system focusing on the whole body, the dual-panel system focusing on the liver region is smaller and more desirable in our situation. However, such a system has a sparser line of response (LOR), which makes image reconstruction even harder.

The non-standard geometry, combined with low-count data, presents challenges for traditional image reconstruction algorithms, motivating our exploration of AI and neural network-based solutions.

PET Image Reconstruction Methods

Positron Emission Tomography (PET) works by detecting pairs of gamma rays (γ) emitted following the annihilation of a positron from a radioactive tracer. The system records the pairs of crystals detected coincidence events, and the time difference between the detection of the two gamma rays, which is known as the Time-of-Flight (TOF). The TOF helps localize the source along the LOR defined by the pair of crystals, while the randomness of the recorded TOF poses the difficulty of knowing the real location on the LOR.

Most Likely Position (MLP) is a straightforward and computationally fast method that directly places events into image voxels based on their LOR and TOF information. To prevent the sampling issue caused by the fixed position of LOR edges for each crystal, the positions of the crystals are randomly perturbed. Its primary drawback is the inability to account for the inherent randomness in TOF measurements, which can lead to lower-quality images while the coincidence time resolution (CTR) is high.

Maximum Likelihood Expectation Maximization (MLEM) is the standard algorithm for PET image reconstruction. MLEM is an iterative, statistics-based algorithm that aims to find the image that

most likely produced the observed data. It uses a statistical model (Poisson distribution) and a system matrix to account for the PET system's physics, including the TOF's randomness. The image can then be solved iteratively using expectation maximization, which can reach the maximum likelihood derived from the statistical model.

Deep image prior (DIP) is a novel technique that uses a deep neural network (specifically a UNet architecture) as a structural prior for image denoising. Unlike typical deep learning models, DIP requires no prior training data. Instead, it trains the network to transform a simple prior image (e.g., a random or anatomical image) into the noisy target image (from MLP or MLEM). The network architecture naturally resists fitting to noise, so the process is stopped early to produce a denoised version of the image.

DIP reconstruction (DIPrecon) is a hybrid method that combines the statistical rigor of MLEM with the denoising capabilities of DIP. The algorithm alternates between updating the image to match the observed PET data (the MLEM step) and refining the image to conform to the structural prior imposed by the neural network (the DIP step). A balancing parameter ρ is used to control the influence of the DIP prior, with a higher ρ placing more emphasis on denoising.

Experimental Design

A series of simulations was conducted using the GATE software package to evaluate these reconstruction methods. The simulation was mainly set as a dual-panel system with a resolution phantom as the source. The phantom was placed in the xy-direction and the zy-direction to simulate an easier and harder problem, respectively. The randomness of TOF was set as CTR equaling 50 ps for the small randomness test, and CTR equaling 200 ps for the practical randomness test. To simulate the low-count data, a portion of the data was randomly selected from all the observed data to generate different levels of low-count data.

Both qualitative and quantitative measurements were used to assess the performance of the reconstruction algorithms. The qualitative performance of the reconstructed images was assessed by directly plotting the axial slices of the reconstructed images. The quantitative performance is assessed using a trade-off analysis between image contrast and noise. Contrast Recovery Coefficient (CRC) measures how well the contrast between the foreground and the background is recovered compared to the reference phantom. Normalized Standard Deviation (NSTD) measures the noise

level in the background. By plotting CRC versus NSTD, the optimal balance between contrast and noise for each reconstruction method can be determined.

Results and Discussion

For visual quality assessment, in low-count scenarios (e.g., 0.1% of data), images from MLP and MLEM are dominated by noise, and the rods in the phantom were indistinguishable. Applying DIP as a denoising step improves the clarity of the MLP images. DIPrecon produces the clearest images with the best-defined features.

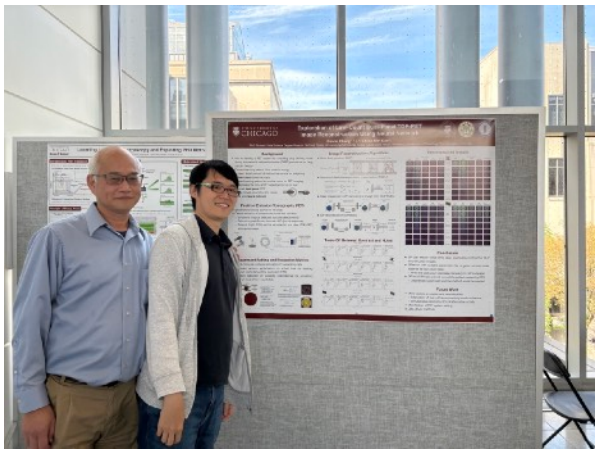
The CRC vs. NSTD plots show that MLEM generally provides a better contrast-noise trade-off than MLP. DIP (applied as a post-processing denoiser to MLEM) and DIPrecon outperform MLEM alone, pushing the curves toward the top-left corner of the plot (higher contrast, lower noise). DIPrecon, with a suitably chosen balancing parameter ρ, demonstrates the best overall performance. The results suggest that a higher emphasis on the DIP component (a larger ρ) is beneficial as the number of counts decreases.

The 200 ps CTR in zy-setting introduces artifacts and blurring that none of the methods, including DIP and DIPrecon, can fully correct. While these methods are excellent for handling statistical noise, they are less effective at correcting systematic errors from hardware limitations.

Future Directions

Several key areas are identified for future work: more realistic simulations for incorporating attenuation and scatter effects from liver tissue and generating more realistic lesion shapes, system modification for exploring personalized adjustments of the dual-panel detector locations to optimize imaging for each patient, and data-driven methods for CTR artifacts correction.

Final Presentation



Final Poster Session

Research at UChicago

Different Styles of Progressing Research

Although many people may expect significant differences between research practices in Taiwan and the United States, my personal opinion is that the fundamental essence remains the same: both involve forming hypotheses or research questions, followed by applying various methods, including a large amount of intellectual and workforce investment, to obtain the results. The main differences are the interaction between professors and students and the laboratory organization.

At UChicago, the relationship between professors and students is more like that of a college with different experiences. While the hierarchical distinctions still exist, communication often takes place in a more equal, peer-like manner. Students are encouraged to express their own ideas, which contributes to a more diverse research environment, though not necessarily a more efficient one. In contrast, at NTU, the social atmosphere emphasizes respecting professors. Students often tend to adopt the opinions of their supervisors. This structure may limit the diversity of research approaches, but it may enhance efficiency due to the long-term experience accumulated by the professors.

A notable difference between UChicago's and NTU's laboratory organizations can also be observed. At UChicago, the laboratories have multiple professors with expertise in different fields. For example, in my lab at UChicago, one professor may outline broad research directions based on accumulated experience and literature, another may break them into concrete, manageable projects for students, and the other may handle hardware and infrastructure. At NTU, however, laboratories are generally organized around a single professor. Even when multiple professors present, they typically collaborate only in areas that overlap with their research directions. It avoids potential conflicts among senior faculty and introduces potential risks of failure when research directions are not on the right track.

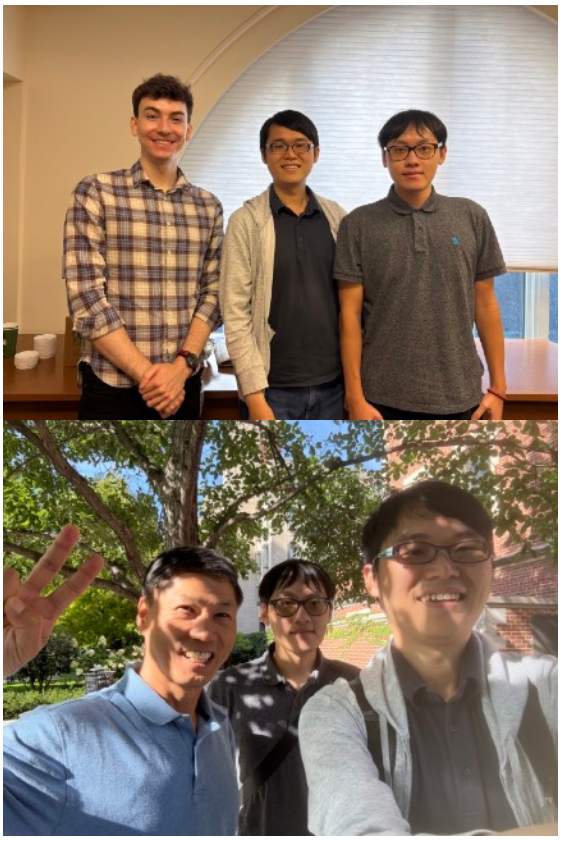
Strength of Taiwanese Students

From my observations, Taiwanese students, especially UCTS fellows, possess notable strengths compared to UChicago students. They often demonstrate stronger discipline and responsibility than their American counterparts. In addition, their academic foundations are solid, enabling Taiwanese master's students to perform at a level comparable to U.S. doctoral students, considering that American PhD students often begin their training immediately after completing undergraduate

studies. If Taiwan's academic environment were more research-friendly and would attract students to do research, students and researchers could achieve even greater global recognition. The current achievements of Taiwanese researchers are already commendable. Still, with a more supportive and flexible research environment, our contributions could reach an even higher standing in the international academic community.

Academic and Career Connection

One main benefit of attending the exchange program is establishing connections for international research and researchers. This exchange program allows us to learn the most modern technology in PET imaging devices. On the other hand, we provide the knowledge in AI and machine learning to help them improve their software development. Based on such exchange of knowledge, we develop an initial research on mixing AI and PET image reconstruction that may be used to develop a mobile region-specific PET device. I will continue on these related topics and hope to contribute more to this field.



Doctoral Student and Professor I met in UChicago (taken with my NTU classmate)

Another great benefit from this exchange is the opportunity to research abroad. I am considering my career after getting my Ph.D. degree. Doing the post-doctoral research at UChicago would be a satisfying choice for me, based on the good experiences over the past ten weeks. It will be helpful for my pursuit of an academic job in the future, broaden my view in my research direction, and be helpful for my academic career.

Live and Events in Chicago

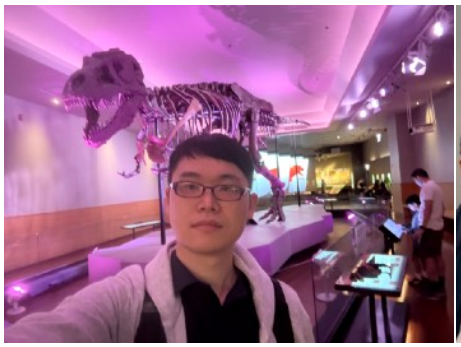
Daily Life in Chicago

Life in Chicago is not as easy as life in Taipei, which reflects in two main aspects: routine meals and public transportation. For the daily meals, the food is not as cheap or as good as the food in Taipei. Therefore, I decided to cook dinner on weekdays with several colleagues. Though I already have lots of cooking experience in Taiwan, I still learned how to prepare meals, balancing delicacy

and time cost. For transportation, Chicago has a good public transportation system, which makes traveling without a car possible. However, the quality of transportation is not as good as that in Taipei. For example, the trains in the MRT system in Taipei are usually clean and quiet, which makes the riders feel comfortable. On the CTA train in Chicago, however, you often see the urine on the chair or floor, and the riders who are smoking weed, which makes the smell in the stations and in the cars uncomfortable. After this trip to Chicago, I think I'm more impressed and will value the transportation system we have in Taipei more.

Site Seeing in Chicago

Chicago has an astonishing city skyline, cultural buildings, and museums. During my stay in Chicago, I visited lots of museums. I had a memorable experience, such as the dragon fossil in the Field Museum, the U-505 submarine in the Griffin Museum, classical paintings in the Chicago Art Institute, modern art in the Museum of Contemporary Art, and the secret behind modern telescopes in Adler Planetarium. I also explore the world of animals and plants in the Sheed Aquarium, Lincoln Park Zoo, and Chicago Botanic Garden. I also took the architecture river tour to enjoy the view of buildings, and visited the Chicago Skydeck and 360 Chicago to enjoy the city skyline.



At Filed Museum

At Art Institute

At Willis Tower (Skydeck)

Not only the static sightseeing, but I also joined the daily entertainment that Chicago citizens may have. Invited by the Graduate Association at UChicago, we joined an MLB baseball game at the Rate Field. The atmosphere on the field is quite different from that of the Taiwanese game. The sound and visual effects are less, but the audience will keep the tension by themselves. Besides the baseball game, I also have a chance to see the Beauty and the Beast

At Rate Field

At Cadillac Palace Theatre

Musical in one of the old theaters, the Cadillac Palace Theatre. The decoration inside the building is classical, but accompanied by the modern effect and music, it creates an unforgettable experience.

Visiting the Taipei Economic and Cultural Office in Chicago

At TECO in Chicago

UCTS students are invited to visit Chicago's Taipei Economic and Cultural Office (TECO). It was my first time visiting a Taiwanese national organization abroad. We were treated to a Taiwanese lunch box and boba milk tea. Within the discussion session, we discuss the current status and possible direction for improving the International status of Taiwan. I also learned about the situation of Taiwan in Chicago. My conclusion, which might be surprisingly simple, is that I can now polish my research and presentation skills to expand the impact from Taiwan into the international academic community.

Establish Connection with Taiwanese in Chicago

Studying abroad is a good chance to establish connections with other Taiwanese people. The UCTS program provides several chances. UCTS held a party to meet with our donors, Taiwanese alumni living in Chicago. Besides it, NTU students were also invited to join a party held by May June, the leader of the NTU Alumni Association in Chicago. During these parties, I met other talented NTU alums working in important positions in various fields. Meeting them not only makes me understand more of the frontline tendencies of the industry, but also fulfills me with their life experiences. It would also be a good connection if I need to work in the related field in the future.

Picnic with Donors

Party with NTU alumni

Conclusion

In summary, I have had a fruitful summer through the UCTS program. It provides progression in research projects, opens up opportunities for my future career, broadens my international view, and establishes a connection to people. As my final comment in my final presentation, this is the best summer I have ever had. All these things happened thanks to the contributions from UCTS programs and NTU OIA. I strongly suggest continuing this program for talented students in the future.