Dismantling the invisible barriers of nationality and discipline in the pursuit of science

In December 2014, my wife Anya and I travelled to Buffalo, New York to visit Buffalo State College (BSC) where Anya's mother, Katherine Conway-Turner, had recently become President. Departing from our home at the Okinawa Institute of Science and Technology (OIST), where Anya works as an art conservator to preserve Okinawan artifacts in collaboration with local museums, and I run a physics research unit specializing in femtosecond spectroscopy – we took the long journey from Japan to the east coast of the states.

Barely off the plane, we headed to BSC for a tour of the art conservation and physics departments to find out about their latest projects.

Sipping tea in the art conservation department, I ended up chatting to established art conservation scientist Aaron Shugar, and art conservator James Hamm, who explained to me the importance of taking cross-sections of paintings to analyze the different layers of paint and other decorative coatings. This kind of cross-sectional analysis enables art conservators to uncover critical information about the history and authenticity of a piece of art, as well as to aid in its restoration.

However, according to Aaron, the conventional approach of taking cross sections by using a scalpel to cut and remove a small piece of the artwork is not ideal and could end up damaging the painting further. Curious about my research, Aaron asked me if it would be possible to create a clean cross-section of a painting using a femtosecond laser. In theory yes, but I had certainly never tried it. I had used femtosecond lasers to engineer opto-electric devices, image electrons in motion in a solar cell device, and study photocarrier dynamics in novel materials. But never had I fired laser beams at a painting.

Anya immediately appreciated the value of this idea and saw it as a good opportunity for my research unit at OIST to partner with the art conservation programs at both OIST and BSC.

Most physicists might have left it there. What would a physicist be doing playing around in the world of art conservation, I thought. But having just begun my career at OIST, a brand-new international research institute based in Japan that prides itself on interdisciplinary research, this seemed like the best opportunity to dip my toes in unfamiliar waters. By using the tools of femtosecond lasers to solve an art conservation problem, I could break down the barriers between these seemingly distinct disciplines and potentially make an important contribution to the study of cultural heritage. And it certainly helped to have my wife working alongside me professionally; after all, we do make a good team in our personal lives.

I made no promises to Anya, Aaron and James. If I could find time to work on this project I would do so with enthusiasm. Nevertheless, before our BSC tour was over, Aaron handed me a package of paintings to work on, if time ever permitted.

At the end of our trip, Anya and I returned to Okinawa with the precious cargo safely stowed in our luggage.

Paintings and Lasers

The paintings sat in my office collecting dust for several months. In the summer of 2015, Anya gave the project a nudge by hiring a new intern from the art conservation department at BSC to pursue our interdisciplinary idea, among other things. And after many months of collaboration between OIST's Femtosecond Spectroscopy Unit, OIST's Art Conservation Program and the Art Conservation Program at BSC, we successfully showed that Femtosecond lasers could in fact be used to cut a tiny cross section from the corner of a painting, with minimal damage to the surrounding area.

Unlike normal lasers that produce a continuous light beam, femtosecond lasers produce extremely short light pulses that last just a few millionths of a billionth of a second. During that seemingly insignificant amount of time the pulses could deliver more power than that needed to launch a shuttle into space. In fact, femtosecond lasers deliver their energy so quickly that there is no time for heat transfer. So unlike conventional lasers that generate enough heat to melt the area surrounding the laser beam, femtosecond lasers can cut through surfaces with extreme precision, without inflicting damage to the surrounding material.

Culminating in a recent publication, our interdisciplinary and international collaboration provided a brand-new technique for analyzing and sampling artwork with far less destruction than conventional tools used in art conservation.

A New Model

Interdisciplinary and international research embodies OIST's core values. By actively discouraging the separation of different scientific disciplines – both metaphorically but also physically within the labs – and having over 50 countries and regions represented by the university community, OIST is really at the forefront of a new model of research and education. In my unit alone, of 13 people, we have 8 different nationalities and we speak over 15 distinct languages between us, including French, Lithuanian, Cantonese, Mandarin, Filipino, Hindi and, of course, Japanese and English. It serves as the perfect microcosm of OIST.

Without the support and administrative structure of OIST, the collaboration between a bunch of physicists and art conservators would probably never have gotten off the ground. The flexibility in funding, personnel, and experimental setup; the sense of trust and teamwork that has developed among the faculty across disciplines; and the willingness of researchers to try innovative, out-of-the-box ideas, all help in the pursuit of successful interdisciplinary projects at OIST.

Though my collaboration with art conservators might seem unusual to many, this sort of research is commonplace at OIST. Since I joined OIST in late 2011, I have witnessed mathematicians working with ecologists, chemists with engineers, and physicists with biologists to solve big scientific problems that no one discipline could solve alone, as well as to innovate at the boundaries of academic disciplines.

Femtosecond light to interface with neurons

As a physicist, one's innate curiosity about the universe naturally extends to areas outside the traditional realm of physics. Thanks to the close-knit community at OIST, I get exposed to worlds entirely outside my own, including that of the neurobiologists.

In a collaboration that grew out of a conversation at our weekly teatime event at OIST, together with Takashi Nakano and Jeff Wickens of the Neurobiology Unit, and Chemists at the University of Otago in New Zealand, we learned of the possibility to manipulate brain activity using femtosecond lasers.

From an informal conversation over tea and biscuits, we ended up working as a team to pre-load liposomal nanostructures with dopamine – a key neurotransmitter in the central nervous system – and use femtosecond lasers to repeatedly release precise pulses of dopamine, as well as other chemicals. Thereby, we successfully developed a technique with the potential to interface with, and artificially replicate the pulsatile, rhythmic biofunctionality of living organisms.

In this truly interdisciplinary research, chemists, neurobiologists and physicists worked together to design an experiment that capitalized on our various areas of expertise. Our latest results demonstrate the applicability of this technique to interface with neural functioning, with implications for future brain and behaviour research.

Femtosecond light to image neurons

Using powerful femtosecond lasers to non-destructively release chemicals in a brain slice may be an unexpected application. But in general, neuroscientists are no strangers to femtosecond lasers, using them ubiquitously to image neurons in 2-photon microscopes.

At a swing dance class at OIST in the fall of 2014, one of OIST's young graduate students – Viktoras Lisicovas working in the Information Processing Biology unit, approached me about the possibility of building a novel type of 2-photon microscope that would allow him to image multiple neurons simultaneously in live *C. elegans*. A traditional 2-photon microscope, where a tightly focused optical beam has to be scanned across the field of view, was too slow to answer his research question about the interaction of the neurons.

So we embarked on a project to build this novel 2-photon microscope recently demonstrated by Silberberg and colleagues, and independently by Xu and colleagues. Instead of focusing the light beams tightly in space, as conventional techniques do, we focused the light beams in time, allowing us to image a larger field of view, and thus multiple neurons in *C. elegans* simultaneously. With the first images just coming out of our microscope, we hope that this collaboration between physicists and neuroscientists will lead to a deeper understanding of the collective behavior of neurons in live *C. elegans* in the years to come.

Whether it is working with art conservators to come up with a new technique to take cross sections of paintings for analysis, collaborating with neurobiologists and chemists to pioneer a new way of manipulating brain activity or enabling neuroscientists to visualize networks of neurons in *C.elegans*, I enjoy working with my colleagues in diverse fields. And I am in the right place for this – with its unique culture, OIST goes a long way in dismantling those invisible barriers between academic departments, seeking to unify nationalities and disciplines in our shared pursuit of knowledge.