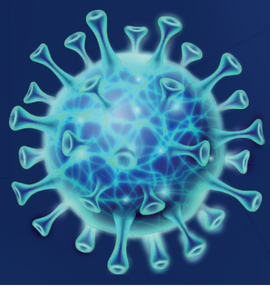
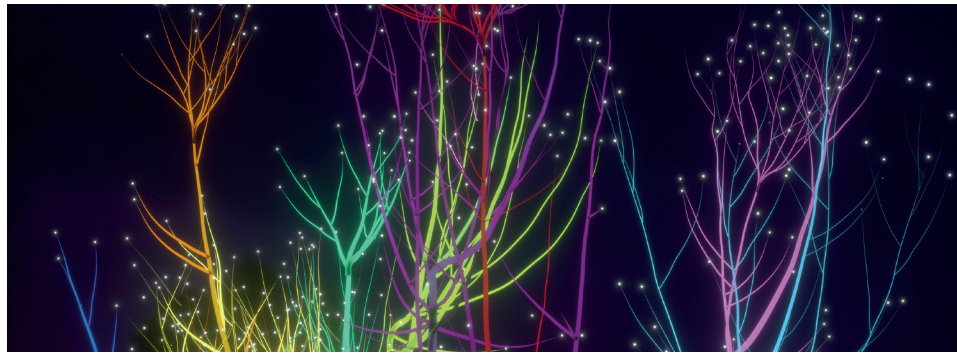


COVID CONTRIBUTIONS

The Pathway to UV Lights that Can Destroy Viruses

UCSB materials scientists work on semiconductors that could transform how we disinfect surfaces, personal protective equipment — even the air we breathe



The COVID-19 outbreak has brought into sharp focus the need to be able to sanitize surfaces, personal protective equipment needed by front-line health workers, and even the air we breathe in shared closed spaces, such as ships and airplanes.

UV lights — those emitting in the very short, ultraviolet, wavelengths — are a promising tool for this purpose. Already, some jails and prisons are using robots topped by a bank of UV lights to decontaminate cells and shared spaces, such as dining halls. UV light damages human skin and eyes, though, so the rooms are emptied before the robots go through, sanitizing everything in them.

For the past twenty years, the Solid State Lighting and Energy Electronics Center (SSLEEC) in the UC Santa Barbara College of Engineering has been a world leader in developing ever-more-powerful and energy-efficient solid-state LED lighting. For about fifteen years, smaller SSLEEC research efforts have been directed at developing LEDs emitting in the ultraviolet wavelengths of 200-280 nanometers (UVC), primarily with an eye on water purification in areas of the world lacking water-treatment infrastructure. UVC lights have been used for decades by municipal water plants, because they destroy the DNA of many microbes, rendering drinking water safe.

While the Sun sends ultraviolet light in the form of UVA and UVB, the best UV light for purifying air and water and for inactivating microbes — UVC — can be generated on Earth only via man-made processes. Until recently, UVC decontamination systems have been enabled not by LEDs, but by mercury-vapor lamps. Among them is the SteriPEN, a water-purification device used by backpackers. If the glass in the SteriPEN breaks, mercury is released, rendering the device useless.

"One big drawback to using mercury lamps for disinfection of enclosed spaces is that they require a lot of voltage to operate, which is difficult to achieve for a portable device should it need to run on battery backup during a power outage," says **Steve Denbaars,** SSLEEC co-director and the Mitsubishi Distinguished Professor. "But LEDs, which are small, non-toxic, run on little power, and are essentially shatter-proof, can go everywhere. You could even imagine having a UV LED on your cellphone to decontaminate it if someone else touches it."

When, in March, UCSB laboratories ramped down in response to the outbreak, exceptions were made for what was deemed essential research. SSLEEC's UV projects qualified and not only continued, but expanded. "Pre-COVID, we had one [PhD] student working on it; now we have five," Denbaars notes. "With COVID, we shifted people from the white-LED projects to the UV LED projects."

He calls COVID a tipping-point application for UVC LEDs, "because you can't decontaminate an entire room by spraying, and you can't decontaminate your food by spraying it with Clorox," he says. "You can't even decontaminate your mask with Clorox, or with alcohol. But you can decontaminate it with UV light. The other way to decontaminate masks is to use vapor hydrogen peroxide, but to do that you have to buy a special reactor, which is expensive, and that process allows you to use the mask only about three times."

A preview of a study that was published in the September issue of the journal *Emerging Infectious Diseases* compared four methods for decontaminating N95 respirators: treating them with UV light, with heat (150 degrees Fahrenheit), with a 70-percent ethanol solution, and with vaporized hydrogen peroxide (VHP).

VHP and ethanol had the highest rate of inactivation of SARS-CoV-2, which causes COVID-19; however, after two rounds of usage, the VHP- and ethanol-treated masks showed marked drops in filtration performance. The heat-treated masks constantly underperformed compared to the UV-treated masks and did not function effectively after two decontaminations.

> "Government people are calling us now and asking what it will take to get UV LEDs to be really efficient."

Further, says **Chris Zollner,** who is completing his fourth year as a PhD student in the SSLEEC, "In this study, the researchers placed the mask far from the UV LED, resulting in a low 'dose' of UV radiation, so they needed a lot of time to get UV disinfection to work well. I suspect that, had they placed the LED closer to the mask, it would have been disinfected much more quickly."

At their current efficiency and power, UVC LEDs are able to decontaminate masks without damaging them, and as power and efficiency increase, Denbaars notes, he expects to see sanitization times come down to a few seconds of exposure.

Denbaars says that the COVID-19 pandemic has ignited the conversation around UV LED research funding: "Government people are calling us now and asking what it will take to get UV LEDs to be really efficient."

Currently, UVC LEDs are only about 3-percent efficient, making them most effective for low-power portable applications, while the LED light bulb you buy at the store is about 60-percent efficient. "We have a twenty-fold improvement we can do," says Denbaars, adding, "It's a complicated process in materials science."

The team, spearheaded by Denbaars, who uses metal organic chemical vapor deposition (MOCVD) to grow the semiconductor materials, as well as UCSB materials professors **James Speck,** who characterizes the new materials, and Nobel Laureate **Shuji Nakamura,** who designs the device, has also developed a new material, made by depositing a thin film of the semiconductor alloy aluminum gallium nitride (AlGaN) on a silicon substrate.

"Current UVC disinfection lamps, such as mercury vapor lamps, have fixed light emission of 254 nanometers," says Denbaars. "However, many bacteria, fungi, and viruses are killed more efficiently at different wavelengths. The AlGaN material system being developed at UCSB allows for greater flexibility in fine-tuning UVC light emission from an LED, which would make targeting specific microorganisms a real possibility. Aluminum gallium nitride is the only semiconductor that provides light of the correct wavelength, and UCSB is a world leader in developing it."

It is expensive and time-consuming to make a functioning UV LED on a sapphire substrate, so UCSB researchers have developed a new process: by replacing the more-often-used sapphire with silicon carbide, they can use much simpler traditional epitaxy methods to grow high-quality AlN and AlGaN materials.

Heating and air-conditioning systems, which recirculate air, are another big target for improved decontamination. Denbaars notes that state-of-the-art high-efficiency particulate (HEPA) filters are made to filter out particles down to three microns in size. Once captured by the filtration system, however, viruses can shrink as they dry out, possibly enabling them to pass through the filter and be recirculated into the airplane or operating room, where they may infect people. In environments lacking HEPA filters, rather than being captured, the viruses are simply redistributed.

With powerful, efficient UVC LEDs, Denbaars says, "You could pass air through a light tunnel to decontaminate it; you just need enough photons to hit enough of the air. It used to be that people thought it would be nice to have contamination devices on subways and ships and other enclosed spaces where people gather in large numbers. The coronavirus has made it priority one."

Long-term, Denbaars says, "The goal is to shift to certain shorter wavelengths of UV that are safe for skin and eyes, so that you could conduct safe decontamination even in the presence of people. You could leave the lights on all the time for applications like hospital operating tables, navy ships and submarines, airplanes, prisons, and so on. I think we're years, not decades, away from that."

Understanding a Pandemic's Disparate Impacts

By nearly every measure, the COVID-19 pandemic has taken a disproportionate toll on the disadvantaged. Thanks to funding from the Pahl Initiative on the Study of Critical Social Issues in the Division of Social Sciences, UC Santa Barbara economics professor **Heather Royer** is studying ways to address that disparity. The Pahl Initiative is a gift of alumni **Louise and Stephen Pahl** to support social science research on topics of pressing social importance.

"As a resident of Santa Barbara County, it is hard not to see the disparate impacts of this pandemic," Royer says."Social science research can help us in understanding the causes and consequences of the pandemic, and can assist in the county's recovery."

Charles Hale, SAGE Sara Miller McCune Dean of Social Sciences at UCSB, said of the research, "It will add to the growing list of ways that we can and must rebuild better after COVID."

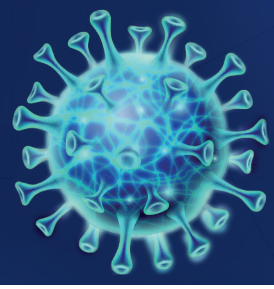
"Santa Barbara County is a microcosm of what's happening both in the state and nationwide," Royer says, "so, what we learn from studying this county can be informative to the local area and more broadly to California and the United States."

Hale also interviewed county organizations and residents to get a sense of their first-hand experiences with the COVID-19 pandemic and their suggestions for possible action going forward. "As a researcher, I can speculate what the drivers are," she explains, "but getting the insights of people 'on the ground' will lead to better-informed policy."

Aside from their COVID research, Royer and one of her collaborators, Mireille Jacobson, an associate professor of gerontology at USC, will investigate the role of the health-care safety net for the disadvantaged. In particular, they'll focus on how the expansion of federally qualified health centers (FQHCs), often referred to as neighborhood health clinics, has increased access to health care for the underserved.

"We will also study how this expansion interplays with hospitals — in particular, as new clinics emerge, do we see a drop in emergency room visits in an area?" Royer notes. "This system of FQHCs provides health care for one in three persons in poverty. The existence of these centers may be critical in the COVID-19 recovery as a provider of primary care for the poor."

Heather Royer



Speeding Toward Faster Tests

As COVID-19 began sweeping the nation in March, Santa Barbara County's Public Health Department faced an acute shortage of reagents needed to conduct the most accepted CDC- and FDA-approved method of testing, called RT-qPCR. In response, a group of faculty members in the Department of Molecular, Cellular and Developmental Biology (MCDB) — professors **Diego Acosta-Alvear, Carolina Arias Gonzalez, Kenneth S. Kosik,** and **Max Wilson** — sprang into action.

First, they gave county public health officers enough reagents to process six hundred tests, but, then, with reagents limited and knowing that testing was an essential tool for fighting the spread of the virus, they began developing a new, faster test based on the CRISPR technology that has revolutionized genomics.

"By mid-March, we knew we had to respond somehow," says Arias Gonzalez.

"It spoke to our sense of social responsibility," adds Acosta-Alvear.

With their efforts deemed essential by the university, the team was allowed to continue working after the ramp-down of campus research, with several members of each professor's lab working in shifts, while adhering to strict social-distancing guidelines.

"We developed the CRISPR assay method so that it's versatile," says Arias Gonzalez. "It can work at high throughput, so you can use robots to set up the reactions and test a large quantity of samples, and you can use the specialized equipment we have here and the specialized personnel who are all well trained to use it."

But, she notes, "Not everybody has fancy equipment, robots, and PhD students and postdocs at their disposal," so, the team set out to optimize the test so that it would be easy to perform without sophisticated equipment. They call the result CREST, which stands for "Cas13-based, Rugged, Equitable, Scalable Testing." It can go anywhere, since it can be run with a cell phone app, a 9-volt battery, and a couple of simple pieces of equipment: a Thermocycler, which is smaller than a toaster, and a small cardboard fluorescence viewer.

> "The campus testing will allow us to detect single cases and test contacts before the virus undergoes exponential spread."

To use it, a sample is collected, processed, and put into the thermocycler, where any SARS-CoV-2 genetic material present is amplified. The material is then detected by the CRISPR enzyme Cas13, which can be programmed to detect SARS-CoV-2 genetic material. When the Cas13 encounters certain bits of SARS-CoV-2, it acts like a kind of molecular "scissors," cutting off the shroud from a bright fluorescent molecule that is visualized by shining a black light on the test tube. CREST allows a binary readout that is easy to interpret: positive samples fluoresce, while negatives remain dark.

The results were robust but relied on a commercial column-based method to extract the genetic material of the virus, which costs five dollars per sample and has limited availability because of the global shortage of testing reagents. To address that, Acosta-Alvear's lab developed a method to extract RNA that is cheap — only about twenty cents per reaction — user-friendly, and makes use of reagents that almost any lab in the world has. As part of the package, they also developed a handheld 3D-printed centrifuge, which effectively facilitates the isolation of nucleic acids from all microorganisms they have tested so far.

The researchers then worked with the UCSB Student Health Center, Cottage Hospital, Pacific Diagnostic Laboratories, and the county Public Health Department to test the assays in two trial runs. In the first, they collected about eight hundred samples from healthy, COVID-19-symptom-free UCSB student, faculty, and staff volunteers between May 28 and June 11. Every sample was tested twice, once with the CDC-approved RT-qPCR test, and once with the UCSB–developed CREST. The researchers' protocol required results to be available in twenty-four hours. The first trial yielded no positive results.

No testing was done during the break between spring and summer quarters, because the campus was largely empty. After the break, a second group of one thousand healthy volunteers was tested between June 26 and July 2. One positive showed up on the 26th, one on the 27th, and one every day, for nine positive tests. Eight were confirmed both with CREST and in a clinical lab, the latter serving as a way to double-check that the assays were robust and reliable.

The results, says Arias Gonzalez, "precisely reflected the community spike among asymptomatic people that occurred two to three weeks after Santa Barbara was declared open," she says, giving the researchers confidence in their assays. "Asymptomatic carriers can inadvertently transmit the virus to others, increasing the potential of covert outbreaks. Surveillance testing will allow us to detect those cases early and take preventive measures to protect our community. Had we been able to test in between the two cohorts, perhaps we could have picked up some cases."

"With further validation, the campus testing will allow us to detect single cases and test contacts before the virus undergoes exponential spread," sysd Ken Kosik, Harriman Professor of Neuroscience. "Think of this as putting out spot fires."

COVID CONTRIBUTIONS

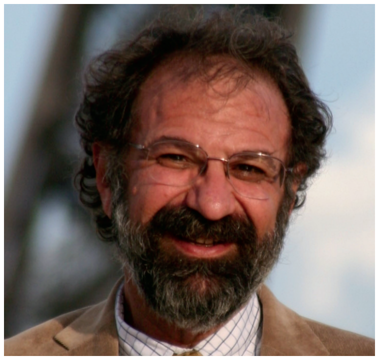
Spreading the Word to Spread the Knowledge

When COVID-19 hit last spring, those seeking a broader understanding of the pandemic and the virus that drives it were served well by a weekly seminar series UC Santa Barbara offered. "Issues, Approaches, and Consequences of the COVID-19 Crisis" brought together experts from UCSB and the Cottage Health System to examine diverse COVID-related topics.

The hour-long sessions convened Tuesdays via Zoom, with each week featuring a different speaker. Free and open to the public, the series was organized jointly by **Ambuj Singh,** a professor of computer science and of biomolecular science and engineering, and **Joseph Walther,** a professor of communication and director of the campus's **Center for Information Technology and Society** (CITS). While the live series ended June 30, recordings of the webinars can be found on the CITS website: **cits.ucsb.edu/spring2020.**

"There is a lot of fear and much that is unknown, and the only way you conquer that is with knowledge and information," says Singh, who also is director of the campus's Data Science Initiative. To that end, he and Walther have brought together an interdisciplinary group having expertise ranging from biology and medicine to public health and ethics to artificial intelligence and machine learning.


Ambuj Singh


Joseph Walther

Speakers from engineering and the sciences included Singh and **Yu-Xiang Wang,** an assistant professor of computer science, presenting on coping with the uncertainty of COVID-19 datasets; mechanical engineering professor **Francesco Bullo** discussing the reliability of various models used to predict the propagation of infectious diseases; and **Carolina Arias Gonzalez,** an assistant professor in molecular, cellular and developmental biology (see story on opposite page), who joined Lynn N. Fitzgibbons, a Cottage Health System infectious disease specialist, to discuss multiple facets of the novel coronavirus and COVID-19. Other talks covered political, social, and economic issues of the pandemic, and included speakers aligned with other research entities involved in the series, such as NOVIM, which was founded at the Kavli Institute for Theoretical Physics with the goal of making complex scientific topics accessible to non-scientists; the Center for Spatial Studies; and the Center for Responsible Machine Learning.

"Celebrities' and authorities' most important message to the public has been that we're all in this together," says Walther, the Mark and Susan Bertelsen Presidential Chair in Technology and Society. "It's the same for academics. The center's motto is that we're interested in problems too big for any one discipline to solve, and that's never been more true than in this case."

What better example of interdisciplinarity, Walther noted, than how social behaviors like distancing affect the impact of a biological threat?

Machine Learning and a Black Swan: COVID-19

How would it spread? How fast and how far? Those were important questions as COVID-19 hit last March. That was when UC Santa Barbara mechanical engineer and applied mathematician **Igor Mezić** and a group of colleagues at his university alma mater in Croatia and at Aimdyn, Inc., in Santa Barbara began working a lot of very late nights. Their goal was an adaptive transition in which they would take an algorithm they had been developing for another purpose, with funding from the Defense Advanced Research Programs Agency (DARPA), and use it to try to predict the spread of the unfolding COVID-19 pandemic.

DARPA is developing artificial intelligence (AI) fundamentals, but the deep-learning and other machine-learning (ML) methods the agency has, Mezić says, "cannot be guaranteed to be correct in many military applications, and there are some applications where the AI has to be one hundred-percent reliable. DARPA keeps looking to fix that, and we were working on a new set of methods."

The group had been developing an ML algorithm that could make accurate predictions in what are known as "black swan" scenarios, so named because they are entirely new and unexpected and therefore have no previously established patterns. COVID-19 was a prime example of such an event and, thus, the perfect test for the algorithm.

"Our group was developing a methodology of prediction for DARPA that would be robust for a situation where somebody just throws a bunch of data at you, like a black swan," Mezić says.

The research, which is based on the Koopman Operator methodology Mezić has been using to develop machine-learning models that are quick to learn and can be readily adopted from one context to another without requiring reams of new data for "retraining," has been completed and the results written up in an article that has been submitted for journal publication. Because the article will be embargoed if it is accepted for publication, currently we can confirm only that, according to Mezić, the Koopman Operator–based AI shows considerable promise in its ability to predict the spread of the novel coronavirus and other "out of the blue" events based on very small data sets. More information on this topic will be forthcoming.

COVID CONTRIBUTIONS

Tweaking the Model

People have behaved differently during the COVID-19 outbreak, than epidemiologists would expect them to under normal circumstances, making it necessary to revamp standard models.

"Some of the early epidemiological models of COVID-19 relied on assumptions about human movement and connectivity that were totally unrealistic, given that most of the country had been shut down," said UC Santa Barbara disease ecologist **Andy MacDonald,** a researcher at the UC Santa Barbara Earth Research Institute.

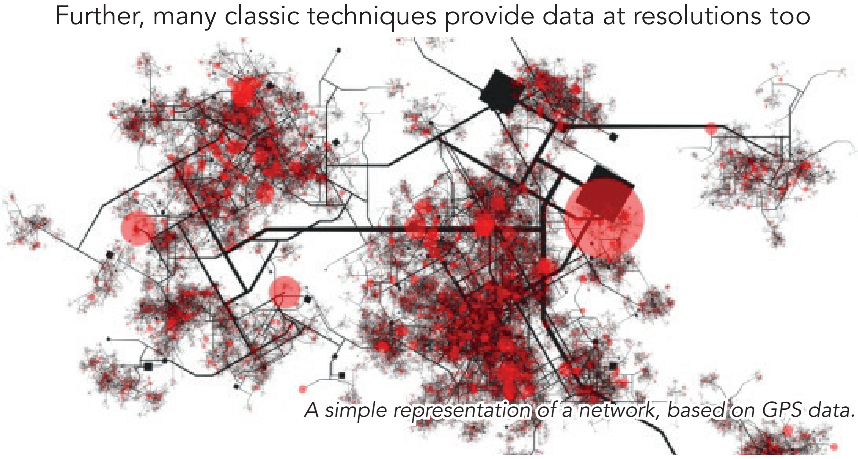
In June, MacDonald, UCSB postdoctoral researcher **Dan Sousa,** and colleagues at Columbia University and UC Berkeley received a one-year, $200,000 grant from the National Science Foundation to address this issue. The funding comes from NSF's Early-Concept Grants for Exploratory Research (EAGER), which supports proposals for high-risk, high-reward research. As MacDonald says, "The ideas may not pan out, but if they do, they have the potential to be transformative."

What he and his colleagues proposed was using satellite and GPS data to build better models. Classic epidemiological models use factors such as commuting and air travel to estimate the degree of connectivity among different population centers. But with people largely staying put as statewide stay-at-home orders were issued, those data sources didn't provide much useful information.

The team planned to use remote sensing to source more-appropriate data to feed into the models. For instance, rather than using commuter-travel data to estimate connectivity, they're looking at other elements, such as night-time lights, with brightness coinciding with the density of built infrastructure; gridded population density, indicating where people are living within those built areas; and mobile phone density, location, and movement, the last being useful in determining the level of social interaction. Such remotely sensed data is also consistent across the entire United States.

"All of these data sources will be brought together to create high-resolution spatial networks of population connectivity, as well as to estimate where people are likely to be, to interact, and to travel," MacDonald says.

Further, many classic techniques provide data at resolutions too



A simple representation of a network, based on GPS data.

Andy MacDonald

low to predict how the disease may spread at small scales, such as among neighborhoods, which can influence the likelihood of subsequent long-distance transmission. The new data sources will provide information at a variety of spatial scales, providing more detailed insights.

The higher resolution should also enable the team to better estimate transmission dynamics as events unfold. "The idea was that if we can use these new data sources to understand how people are interacting with each other, we might be able to better track and predict the extent and speed of transmission, say, from a hotspot that is opening up to a neighboring county that is still closed," MacDonald explains.

And while, as he says, "The human-behavior component of the COVID pandemic is really challenging," causing problems for models, he believes that the reason he and his colleagues got the funding was that their approach could be useful not only for COVID, but also for seasonal flu or for anything that propagates through a network.

"We've shown that by using this kind of data, we can build in a lot more realism than we could in the past," he explains. "Earth-observation data is getting so refined, both temporally and spatially, and if we build in some of these new data sources that are coming on line, then maybe we can do a much better job of modeling these sorts of [spatially propagating] processes than we could in the past."

A month and a half into the project, MacDonald said, "We are all adapting to changing times and changing scientific needs."

Powering up for PPE

As the nation faces its second shorage of personal protective equipment (PPE) during the post-Thanksgiving surge in COVID cases, replicating what occurred last spring, we remember well how UC Santa Barbara faculty and staff responded from the outset.

While students, faculty, and staff were sent home, **David Bothman,** manager of the Microfluidics Lab and the Innovation Workshop, both in the university's California NanoSystems Institute (CNSI), worked alone to design and 3D-print face shields to augment other protective equipment worn by health professionals. He also created an online portal where people on campus could sign up to help. The UCSB Engineering Machine Shop also contributed PPE, joining a number of scientists and engineers who put aside their own work to support the community through the COVID crisis.

In CNSI's well-equipped workshops — which include 3D printers, laser cutters, and a range of other tools — some three hundred faculty and student users from ninety different research groups and CNSI Incubator companies can build scientific instruments and prototypes of their inventions.

COVID CONTRIBUTIONS

Vial Business

A protective vial for medicine is nearly as important as the medicine itself.

With vaccines for the novel coronavirus becoming available, shipping vials of it safely around the world is a question of packaging. UCSB chemical engineer **Glenn Fredrickson** recently worked in an advisory capacity with the American drug company SiO2 to develop a new material coating for vials and syringes.

Fredrickson is a world expert on creating computer simulations of possible soft-material polymers and the monomers used to make them. The coating he helped design, he said in an article that ran in the *Santa Barbara News-Press*, "solves significant challenges in the commercialization of vaccines and biological drugs, which presently cannot be solved by glass or plastic vials. Bringing this advanced coating to market will enable pharmaceutical manufacturers to safely and more rapidly deploy their critical products."

The Mitsubishi Chemical Professor said that the new vials prevent glass particles from flaking off and entering the drug solution and can withstand extreme temperature changes, prevent breakage and thermal stresses, and prevent silicone oil from getting into the drug solution. "You want a package that can handle a major temperature change from room temperature to a really cold temperature," he said.

AI for Local Predictions

From the beginning of the pandemic, we have been barraged by COVID data. Often, local information has mattered to us most.

"We are all overwhelmed by the data, most of which is provided at national and state levels," said **Xifeng Yan,** a UC Santa Barbara computer science professor and Venkatesh Narayanamurti Chair. "Parents are more interested in what is happening in their school district and if it's safe for their kids to go to school in the fall."

Until now, however, few forecasting websites have provided reliable local information. Yan and fellow UCSB computer science faculty member, assistant professor **Yu-Xiang Wang,** the Eugene Aas Chair, have developed a novel forecasting model, inspired by artificial intelligence (AI) techniques, to provide timely information at a more localized level, which officials and anyone in the public can use to help make decisions related to protecting public health.

Their project, titled "Interventional COVID-19 Response Forecasting in Local Communities Using Neural Domain Adaption Models," received a nearly $200,000 Rapid Response Research (RAPID) grant from the National Science Foundation in late April.

"The challenges of making sense of messy data are precisely the type of problems we deal with every day as computer scientists working in AI and machine learning," says Wang. "We are compelled to lend our expertise to help communities make informed decisions."

The researchers developed an innovative forecasting algorithm based on a deep-learning model called Transformer. The model is driven by an "attention mechanism," which intuitively learns how to forecast by learning what time period in the past to look at and what data is the most important and relevant.

"If we are trying to forecast for a specific region, like Santa Barbara County, our algorithm compares the growth curves of COVID-19 cases across different regions over a period of time to determine the most-similar regions. It then weighs those regions to forecast cases in the target region," explained Yan.

In addition to COVID-19 data, the algorithm also draws information from the U.S. Census to factor in hyper-local details when calibrating the forecast for a local community.

"The census data is very informative because it implicitly captures the culture, lifestyle, demographics, and types of businesses in each local community," said Wang. "When you combine that with COVID-19 data available by region, it helps us transfer the knowledge learned from one region to another, which will be useful for communities that want data on the effectiveness of interventions in order to make informed decisions."

Yan and Wang plan to make their model and forecasts available to the public on a website and collect enough data to forecast nationwide. "We hope to forecast for every community in the country, because we believe that when people are well informed with local data, they will make good decisions," said Yan.

Men of AI action (from left): Xifeng Yan and Yu-Xiang Wang