Research at national laboratories tends to be done on very interdisciplinary teams. Projects tackle real-world problems using mathematics and other fundamental sciences. Solutions are then implemented in software or hardware to be delivered to a government sponsor. This full life cycle requires subject matter experts, research scientists (like mathematicians), and software and hardware engineers. In this GovMath column we see two examples of real-world problems and their interdisciplinary solution. First, from Oak Ridge National Laboratory, mathematicians and data scientists work with automotive engineers to secure vehicle networks. Then, from Lawrence Berkeley National Laboratory, climate researchers use mathematical models to understand climate change and hurricanes.

Mathematical Approaches to Secure In-Vehicle Networks

Robert A. Bridges

Modern vehicles rely on scores of small computers called electronic control units (ECUs) that continually communicate life-critical messages, e.g., wheel speeds and steering angle, through a few controller area networks (CANs). Originally designed as a closed network for the life of the vehicle, CAN protocol developed bereft of security features (e.g., authentication or encryption). For emission testing, updates, and other diagnostics, vehicle CANs are now physically accessible, but this comes with vulnerability to cyber attack. Mandatory on-board diagnostic ports (OBD-II) provide adversaries with direct access to the vehicle. Remote attacks, e.g., via Bluetooth or cellular connections, are possible but require deep expertise. In short, the critical networks for vehicle functionality are exposed to remote and local cyber attacks with little to no built-in defenses. Most notably, the infamous 2015 research of Miller and Valasek [Miller, Valasek] exhibited a remote takeover of a Jeep's brakes resulting in a massive recall and ample media coverage.

While the CAN protocol allows anyone to craft and send or passively monitor packets, original equipment manufacturers (OEMs e.g., Ford, GM) employ proprietary (secret) encodings, packing multiple signals or messages with potentially different formats into each CAN packet. In short, one can see or form packets, but how the constituent bits are translated to functional values is not public and varies per make, model, year, and even trim! Hence, pioneering after-market solutions for vehicle-security is a problem of personal and national security ripe for contributions of mathematicians and data scientists.

Oak Ridge National Laboratory (ORNL) has entered this research space as a collaboration of on-going cyber security research and ORNL's National Transportation Research Center. Our initial efforts along with others [Moore, et al. 2017; Gmiden, et al. 2016; Song, et al. 2016] use stationary stochastic processes to model timing properties of a given vehicle's messages and identify injected signals. We exhibited an after-market, plug-in detector prototype that can self-tune in a matter of minutes learning timing char-

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Robert A. Bridges is a Research Scientist in the Cyber & Applied Data Analytics Division at Oak Ridge National Laboratory. His email address is `bridgesra@ornl.gov`.

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acteristics of the packets, then accurately identify packet injections to the CAN. Because various signals in the CAN data are communicating properties of related subsystems, we expect many covariates in these signals (e.g., pedal angle and vehicle speed). Attacks that seek to change vehicle states abruptly may manipulate the messages in an unexpected and discontinuous way. To test this hypothesis, we employed manifold learning techniques to learn a lower dimensional representation of CAN data and found that testing on emulated attacks shows a discontinuous jump in the lower dimensional representation providing a novel avenue for detection [Tyree, et al. 2018]. The above method is a "black box" method (knowing nothing of the data's meaning, but identifying correlations mathematically), which detracts from interpretability. We seek to expand the method by developing a pre-processing algorithm to tokenize (partition) and translate the CAN packets into their encoded messages. Our process involves regression and optimal packing techniques to accurately decode many of the tested vehicles' CAN data.

This ongoing research is a collaboration of mathematicians, data scientists, computer scientists, and automotive engineers and hopefully provides an example of the exciting interplay a mathematician can find in an applied research setting seeking real-world impact. Contributing researchers include Miki Verma (ORNL), Zachariah Tyree (GM), Samuel Hollifield (ORNL), Michael Iannacone (ORNL), Michael Moore (ORNL), Frank Combs (ORNL), and Michael Starr (USAF).

Robert A. Bridges

The Effect of Climate Change on Hurricanes

Michael F. Wehner and Christina M. Patricola

The past two Atlantic hurricane seasons have seen a number of particularly devastating storms. Hurricanes Harvey, Maria, Irma, Florence, and Michael affected millions of people in both the United States and the Caribbean island nations. As theoretical and climate modelling evidence provides solid support that the most intense hurricanes will become even more intense in a warmer world [Walsh et al., 2014], it is natural to ask whether such changes have already occurred. Although trends in observed Atlantic hurricane statistics are difficult to detect due to natural variability and a limited period of consistent observations, it is now possible to use extreme weather event attribution techniques borrowed from epidemiology to answer such questions. The CAlibrated and Systematic Characterization, Attribution, and Detection of Extremes (CASCADE) group, a DOE BER Scientific Focus Area at the Lawrence Berkeley National Laboratory has been refining these techniques to apply to individual intense storms.

Recently, we published a paper in *Nature* [Patricola & Wehner, 2018] examining 15 different intense historical tropical cyclone events using a publically available weather forecast model configured to simulate these storms in two ways. The first, a hindcast of the storms under actual observed environmental conditions, was compared to a second, counterfactual simulation under conditions such that humans had not warmed the planet. In order to most accurately simulate these storms, we used the Weather Research and Forecasting (WRF) model configured at resolutions down to 3 km, and 18 million processor hours on Cori KNL, a Cray XC40 at the National Energy Research Supercomputer Center (NERSC), also located at the Berkeley Lab. There are multiple ways to construct a simulated counterfactual world. We used previously performed global climate model simulations configured both with and

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Michael Wehner is a Senior Scientist in the Computational Research Division at LBNL. His email address is `mfwehner@lbl.gov`.

Christina Patricola is a Research Scientist in the Climate and Ecosystems Sciences Division at LBNL. Her email address is `cmpatricola@lbl.gov`.

without human changes to the composition of the atmosphere to estimate anthropogenic changes to atmospheric temperatures and humidity and ocean-surface temperatures and humidity. These were applied to the observed quantities used as initial and boundary conditions of the actual hindcast to generate a "hindcast that might have been" in the absence of climate change. This enables the attribution of the human influence on these storms interpreted in a Pearl causal framework [Pearl, 2009].

We found that although the expected increase in the wind speed of intense hurricanes due to human induced global warming has not yet emerged, it will by the end of the twenty-first century. However an increase in extreme hurricane precipitation has already emerged in our simulations and in some cases is greater than expected from thermodynamic considerations alone. These simulations indicate that global warming can cause a structural change in the storm dynamics that causes precipitation in the most intensely raining part of the storm to increase the most. This plausible mechanism of dynamical changes in intense hurricanes in a warmer world explains previously unexplained results from four independent studies of Hurricane Harvey (including our own). These found extreme precipitation increases in excess of that expected from the 19th century Clausius-Clapeyron relationship that establishes a relationship between temperature and saturation specific humidity [Risser & Wehner 2017; van Oldenborgh et al. 2017; Wang et al. 2018], and an increase in the probability of extreme rainfall from hurricanes like Harvey due to climate change [Emanuel 2017].


Michael F. Wehner


Christina M. Patricola

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