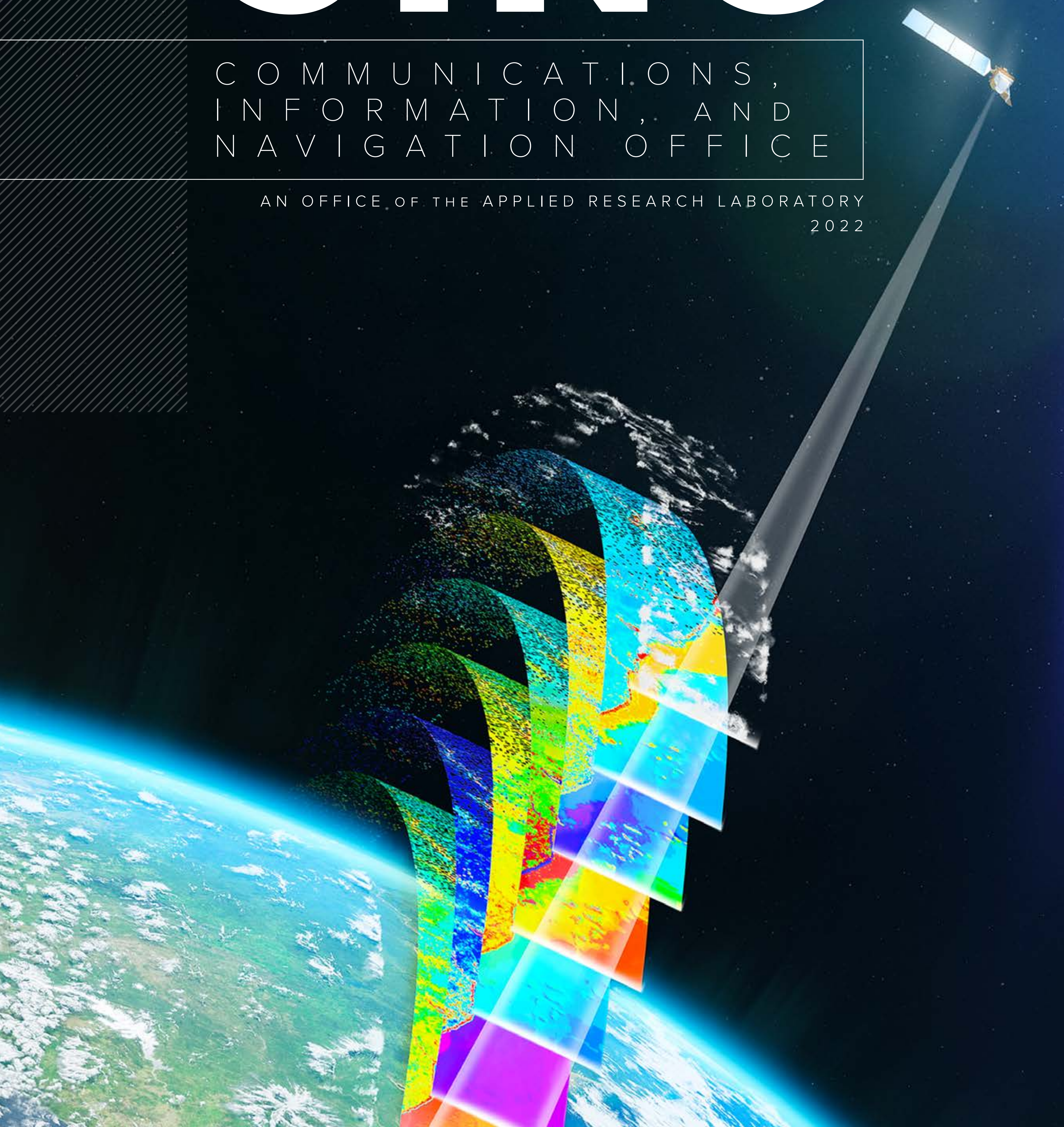
CINO

COMMUNICATIONS, INFORMATION, AND NAVIGATION OFFICE

AN OFFICE OF THE APPLIED RESEARCH LABORATORY

2022




OLD MAIN

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INTRODUCTION

The Applied Research Laboratory at Penn State (ARL) was established in 1945 at the request of the U.S. Navy. According to the strategic guidance from the Department of Defense (DoD) and U.S. Navy leadership, the United States will face an ever more challenging international and domestic security environment and our armed forces must be prepared to operate in an environment in which every domain — surface, undersea, land, air, space, cyberspace, and the electromagnetic spectrum — is contested. ARL supports our research sponsors in these domains by delivering disruptive innovation at the speed of relevance.

As a DoD designated University Affiliated Research Center (UARC), ARL maintains essential research and development capabilities defined as our core competencies. ARL responds to evolving sponsor requirements. By doing so, we remain relevant even during times of rapid change. ARL is a strong and resilient organization because of the mission-focus and dedication of our people.

ALLAN SONSTEBY
Executive Director
The Applied Research Laboratory

ABOUT CINO

Formed in 1998, the Communications, Information, and Navigation Office (CINO) at Penn State's Applied Research Laboratory is a research and development center focused on prototyping and delivering advanced sensing, communications, cyber, geospatial, analytic, and visualization capabilities required by our sponsors.

CINO is a learning-centric organization that cultivates an environment where creative ideas and people thrive for the betterment of our national security mission. Our talented team of world-class researchers concentrate on the collection, analysis, processing, exploitation, transportation and visualization of signals, data and information.

Cyberspace and the wider information environment are our focus — by leveraging our expertise in information and communication technologies (ICT), and navigation systems, we evolve ideas from concepts, through design, prototypes, testing and evaluation.

CINO's DoD and other USG sponsors benefit from an established, trusted relationship.

CINO provides the cutting edge technology development, analysis, tools, and other capabilities that effectuate:

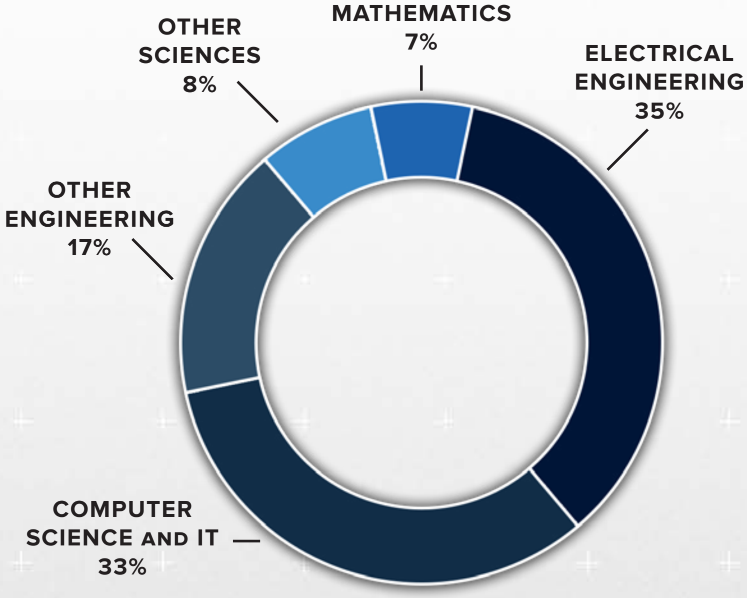
- Cyber- and electromagnetic- maneuver warfare (EMW)
- Special communication
- Precision navigation and precision geolocation
- Decision advantage
- Cyber forensics and cybersecurity
- DevSecOps automation
- Enhanced warfighter effectiveness via real-time support
- Geospatial Imagery, Data Science, and advanced visualizations

Our mission focus spans the physical warfighting domains: land, air, space, maritime, electromagnetic spectrum, and cyberspace. We offer enhanced agility and the ability to rapidly innovate and provide prototypes that meet the national security needs sought by our sponsors for their missions.

OUR PEOPLE

CINO employs nearly 300 people, which is approximately 22 percent of the total ARL workforce. We are a rapidly expanding organization that has experienced significant growth over the last five years not only in terms of project funding, but also with our total number of funded projects.

The majority of our staff are engineers. Research and Development engineers comprise 59% of our workforce, while research faculty accounts for 8% of CINO's ranks.



Acoustics, Aerospace Engineering, Agricultural Science, Astrophysics, Bioengineering, Business Administration & Management, Business Education, Communications Studies, Computational Science and Engineering, Computer Automation Maintenance, Computer Engineering, Computer Management, Computer Science, Cyber Security, Ecology, Electrical Engineering, Electro-Mechanical Engineering, Engineering, Engineering Acoustics, Engineering Physics, Engineering Technology, Environmental Control, Game Design, Geography, Imaging & Data Science, Industrial Engineering, Information Sciences and Technology, Law, Leadership & Information Technology, Letters Arts and Sciences, Literature, Manufacturing Engineering, Marine Engineering, Materials Science and Engineering, Mathematics, Mechanical Engineering, Mechatronics & Robotics, Meteorology, Nuclear Engineering, Operations Research, Pattern Recognition, Petroleum and Natural Gas Engineering, Physics, Political Science, Security Studies, Software Engineering, Soil Science, Statistics, Strategic Studies, Systems Engineering

ISAAC R. PORCHE, III, PH.D.

DEPUTY DIRECTOR, ARL

OFFICE HEAD, CINO

Dr. Porche joined ARL in 2020 and leads the research scientists, engineers and supporting staff in CINO. His past positions include serving as a research scientist and chief engineer at General Dynamics Missions Systems and various research and management positions at the RAND Corporation, where he worked for more than two decades. He received his Ph.D. in electrical engineering from the University of Michigan in 1998.

ERIK LENZING, PH.D.

DEPUTY OFFICE HEAD, CINO

Dr. Lenzing has spent more than 15 years supporting ARL's mission. His expertise is in the area of applied electromagnetics, where he has provided technical leadership as well as direct engineering support in the field and in the laboratory. Dr. Lenzing is currently an ARL Fellow, ARL's preeminent technical distinction, granted in recognition of his record of outstanding and sustained technical achievements.

KRISTOFFER GREENERT

DIVISION HEAD

ADVANCED SCIENCE AND TECHNOLOGY

Kris Greenert has been with ARL for over a decade and has provided technical and programmatic support to key CINO sponsors in the areas of electromagnetic propagation, antenna development, and communication system test and evaluation.

JULIE BOWN

DEPUTY DIVISION HEAD

ADVANCED SCIENCE AND TECHNOLOGY

Julie Bown has over 30 years' experience managing personnel and programs in support of DoD and IC sponsors. Her experience spans all aspects of the research and development process, specializing in systems engineering. Julie's areas of expertise include the demonstration and experimentation of new and emerging technologies in operationally relevant environments, as part of the Thunderstom experiments, which support the expedited delivery of cutting-edge technology to the warfighter.

DAVID JENKINS, PH.D.

DIVISION HEAD

COMMUNICATIONS AND SIGNAL PROCESSING

Dr. Dave Jenkins has been at ARL for over 20 years and has led a number of cross-disciplinary projects focused on manipulating acoustic and radio frequency electromagnetic fields, applying and developing statistical signal processing algorithms, and applying state-of-the-art machine learning algorithms.

RAECHELLE SAYLOR

DEPUTY DIVISION HEAD

COMMUNICATIONS AND SIGNAL PROCESSING

Raechelle Saylor brings over 15 years of experience in computer programming and software engineering to ARL. Prior to joining ARL, she had a career in the intelligence branch of the Army. In addition to her technical leadership, she has a focus on engaging the next generation of engineers through our student programs.

SHANE FLINT

DIVISION HEAD

CYBER, MODELING AND SIMULATION

Shane Flint has more than 15 years in IT, cyber operations strategy, and technological infrastructure management. Shane joined ARL in 2021 after a long and successful career in the Air Force as part of the original cadre of the Air Force's cyber warriors. He previously led a cyber operations unit for Raytheon.

SHAWN HOUGH

DIVISION HEAD

GEOSPATIAL, IMAGING, AND DATA SCIENCE

Shawn Hough has been with ARL for nearly 25 years.

His area of expertise spans the sciences underlying geospatial intelligence.

LEE INSLEY

DIVISION HEAD

NAVIGATION RESEARCH AND DEVELOPMENT

Lee Insley has nearly 25 years of experience with his division. His immense experience and expertise includes systems engineering, algorithms and analysis, and simulations and testing.

TIMOTHY SHAW

DIVISION HEAD

VISUALIZATION AND DECISION SUPPORT

Tim Shaw has supported ARL for over 20 years and was the original architect of CINO's efforts in augmented and virtual reality. His past work includes virtual environments applied to nuclear energy systems design, and human-centered data fusion.

OUR RESEARCH DIVISIONS

In support of the University's scientific discovery mission, CINO's research divisions engage with faculty, staff, and students across the Laboratory and other Penn State colleges and institutes to perform basic and applied scientific research. We work collaboratively to expand knowledge in areas ranging from foundational mathematics, physics, materials, and natural phenomenology through highly applied engineering and information disciplines.

Our students, faculty, and staff excel at investigating real-world problems and use highly specialized knowledge and equipment to solve them. We stand at the intersection of innovation and industry, always in pursuit of excellence through discovery.

ADVANCED SCIENCE AND TECHNOLOGY (AST)

The Advanced Science and Technology Division focuses on nascent technologies in the areas of electromagnetics, electromagnetic maneuver warfare, quantum sciences, and sensors. Through cross-Division and cross-Office collaborations, AST provides foundational basic and applied research products in these areas to benefit our sponsors.

COMMUNICATIONS AND SIGNAL PROCESSING (CSP)

The Communications and Signal Processing Division supports the DoD and IC by providing basic and applied research expertise to develop and prototype advanced communications systems and associated technologies. CSP supports the transition of these prototype capabilities to operational utility.

CYBER, MODELING AND SIMULATION (CMS)

The Cyber, Modeling and Simulation Division conducts research and development on full spectrum cyber capabilities, providing warfighters with strategic and operational cyberspace superiority in conjunction with the ability to achieve and maintain information dominance. A cyber center of excellence, CMS researches, develops, and delivers to sponsors a diverse range of innovative, forward-thinking cyber capabilities spanning the entire electromagnetic spectrum. Our speed and agility provide distinct advantages toward achieving cyberspace domain dominance.

GEOSPATIAL IMAGE AND DATA SCIENCE (GIDS)

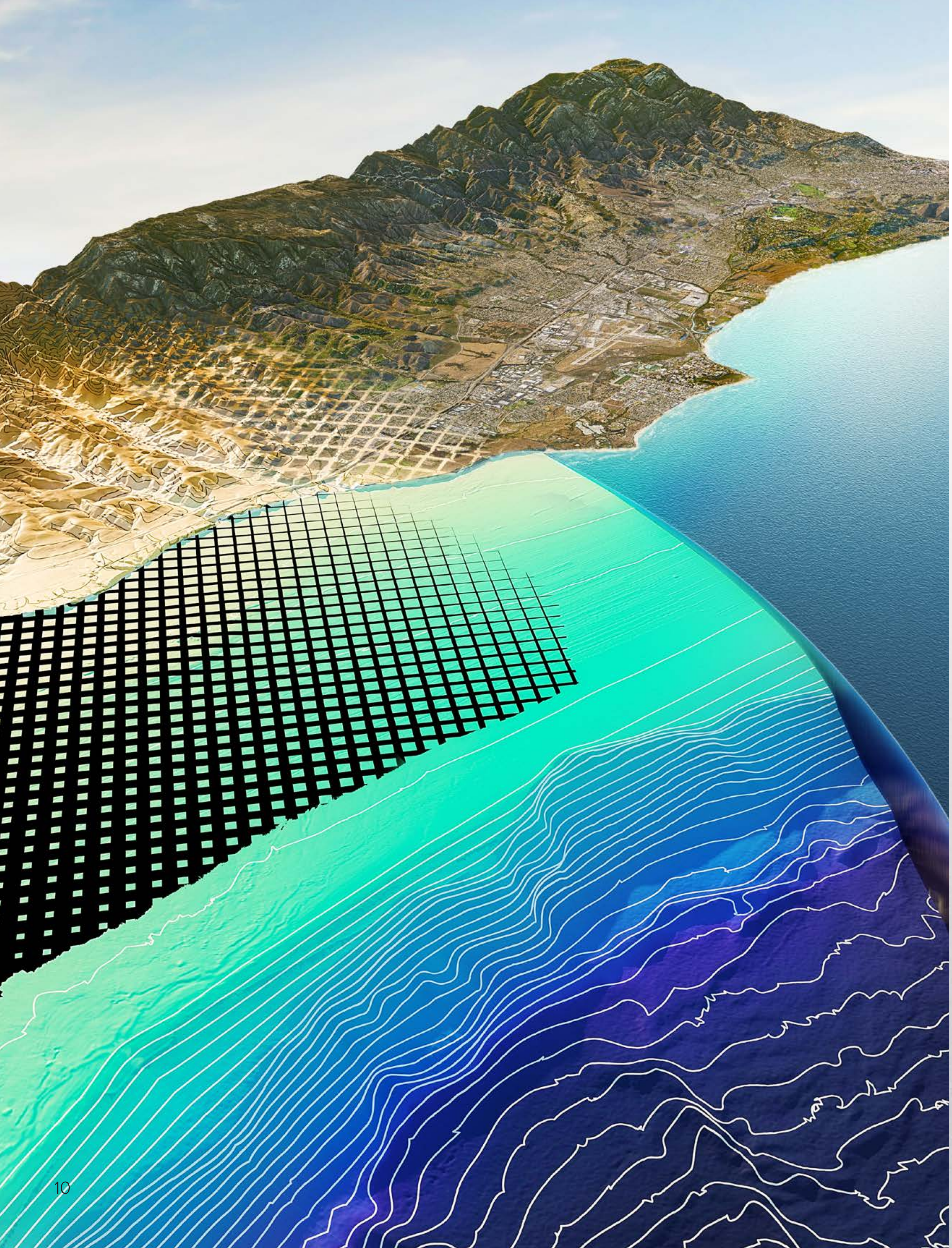
The Geospatial Image and Data Science Division supports the National System for Geospatial Intelligence (NSG) by leveraging expertise in the fields of Geospatial, Image, and Data Science to advance each NSG partner's mission set.

NAVIGATION RESEARCH AND DEVELOPMENT (NRD)

The Navigation Research and Development Division performs precision navigation research, development, testing, and evaluation to meet current and future sponsor mission needs. NRD provides system engineering and technical advice for transitioning new technology and advanced capabilities into military platforms by leveraging specialized scientific and engineering navigation experts and a unique testing facility.

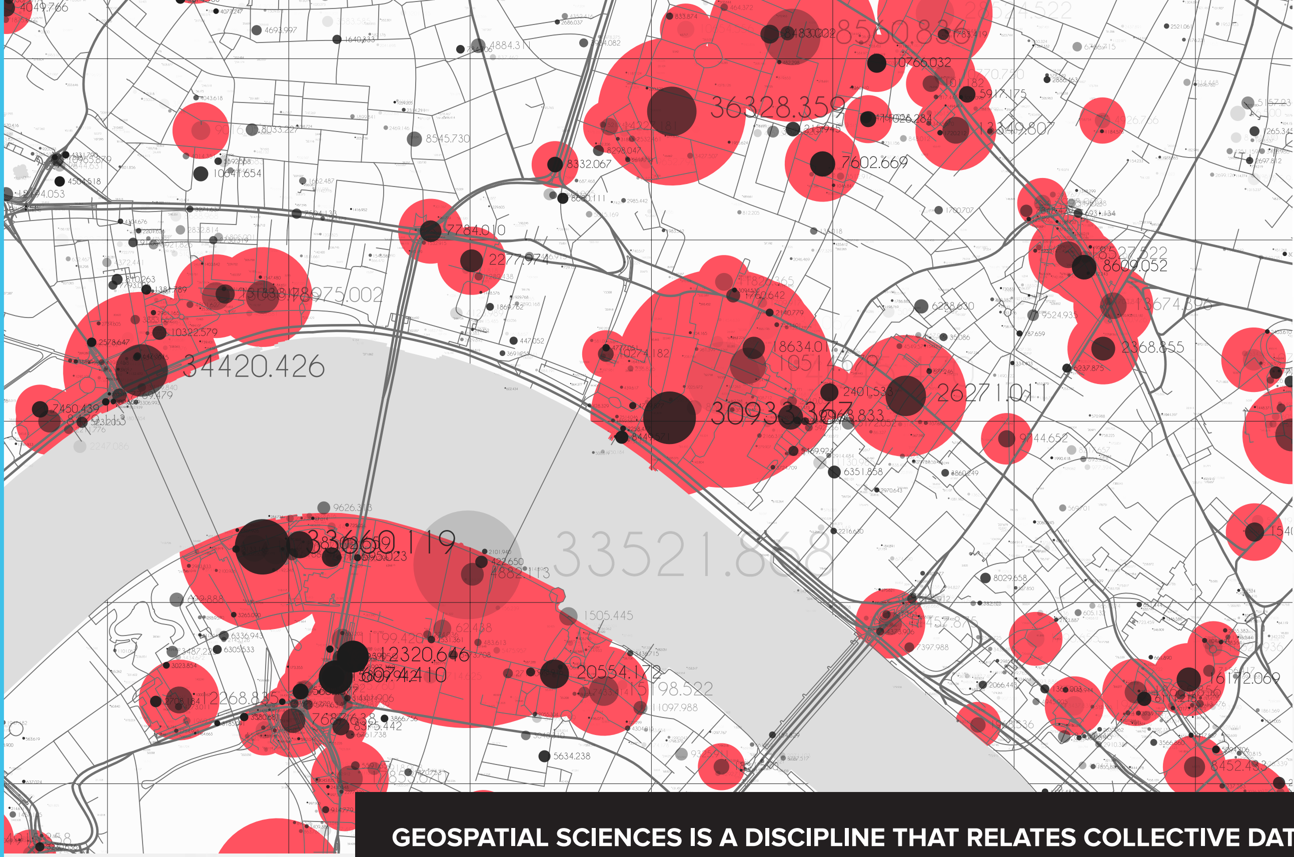
VISUALIZATION AND DECISION SUPPORT (VDS)

The Visualization and Decision Support Division researches, develops, and applies technical innovations that provide decision advantage through the use of visualizations, analytics, geographic information systems, simulations, and collaboration technologies.



CINO SPOTLIGHT

GEOSPATIAL, IMAGE, AND DATA SCIENCES DIVISION

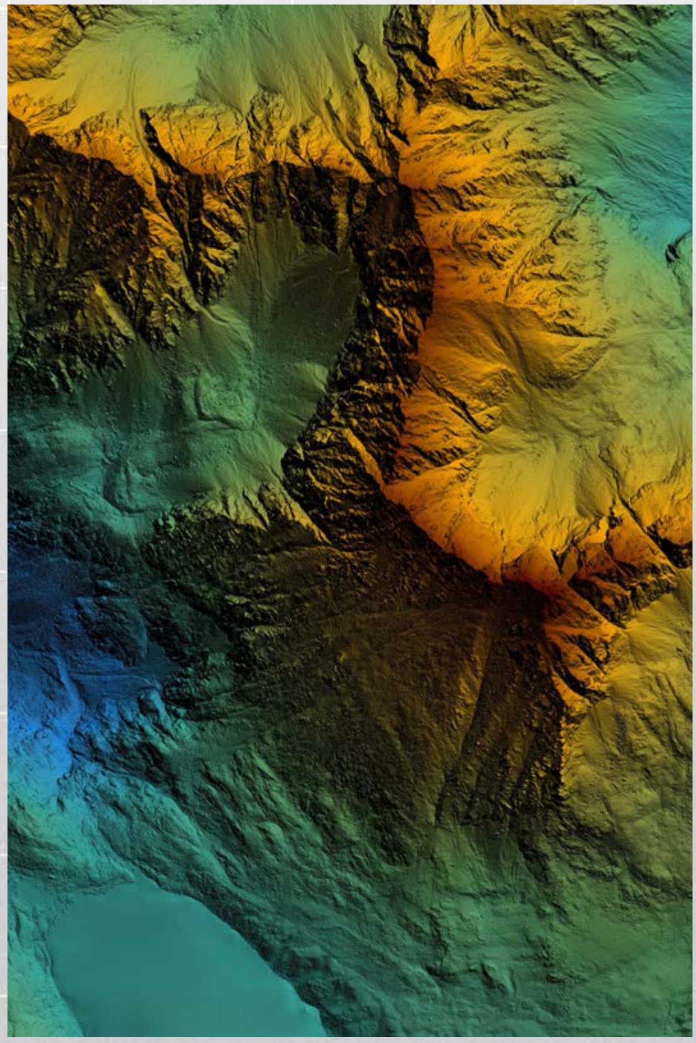


GEOSPATIAL SCIENCES IS A DISCIPLINE THAT RELATES COLLECTIVE DATA AND GATHERING TECHNOLOGY WITH GEOGRAPHIC OR LOCATIONAL INFORMATION.

ABOUT THE GEOSPATIAL, IMAGE, AND DATA SCIENCES DIVISION

The Geospatial, Image, and Data Sciences Division (GIDS) focuses on Geospatial Intelligence (GEOINT) and its supporting disciplines. Our team of researchers includes image scientists, mathematicians, computer scientists, engineers, geographers, and meteorologists. This interdisciplinary expertise provides insight that may not be readily available in less technically robust organizations.

Our division's focus revolves around automating mundane tasks and augmenting higher order analysis and production for analysts. Our expertise in image processing, computer vision, machine learning, geographic information systems (GIS), geospatial and geo-temporal analysis, multiple phenomenology and information fusion, Natural Language Processing, Activity Based Intelligence, and sensor evaluation provides a strong base for tackling difficult government problems.



ROLES, FUNCTIONS, AND SERVICES

TRUSTED AGENT

Under this designation, we deliver subject matter expertise to the government free of both personal and organizational conflict of interest. We act in the best interest of government needs and requirements. This designation is required to be followed within our UARC charter for all work performed for the government.

ARL strives to deliver maximum utility to our sponsors and partners.

NON-PROPRIETARY RESEARCH AND DEVELOPMENT

In support of government sponsors' interests, ARL strives to deliver maximum utility. This includes code delivery to community repositories and academic publications. Our research on the information content of specific sensor modalities for machine learning contributes to the current state of knowledge in this field.

ALGORITHM DEVELOPMENT

ARL develops GEOINT algorithms. An algorithm is an automated routine that processes, analyzes, or transforms data to aid analysts and decision makers. We are experts in the design, tailoring, and customization of algorithms for specific problem areas within GEOINT and can implement algorithms in most programming languages and environments.

We are experts in the design, tailoring, and customization of algorithms for specific problem areas within GEOINT.

ADVANCED PROTOTYPING

ARL develops advanced GEOINT processing prototypes for our sponsors. Our advanced prototypes automate processing of geospatial data and imagery, interweaving multiple algorithms into a single system designed for a specific purpose.

ANALYTICS/ANALYTICAL AND PRODUCTION WORKFLOWS

ARL develops analytical and production workflows with a focus on highly complex GEOINT problems that require collaboration between technology developers and subject matter experts. For this work, we follow a data sciences research and development (R&D) approach, combining automated and manual operations into a workflow designed to answer specific intelligence questions or provide deeper insight into complex GEOINT problems.

We excel as a metrics and evaluation service provider and also as a participant on a larger metrics and evaluation team.

PROTOTYPE INTEGRATION

ARL integrates advanced GEOINT processing prototypes into existing analyst tools and within cloud-based service endpoints. These include the open source and commercial analyst tools as well as enterprise services such as AWS, C2S, and Cloud Foundry.

METRICS AND EVALUATION WORKFLOWS

ARL designs meaningful metrics and evaluation processes for algorithms, analytics workflows, machine learning, deep learning, and advanced GEOINT processing systems. We excel as a metrics and evaluation service provider and also as a participant on a larger metrics and evaluation team.

SAMPLE PROJECTS AND PROGRAMS

DATA FUSION AND ANALYTICS

In a tsunami of data, fusion and enrichment can save time, increase confidence in assessments, and lead to new insight. ARL leverages an array of methods for co-registering data.

We have developed tools for automating enrichment of shapefiles from imagery and 3D sources.

DATA ANALYTICS, METRICS, AND EVALUATION USING AN EXPERIMENTALIST'S APPROACH

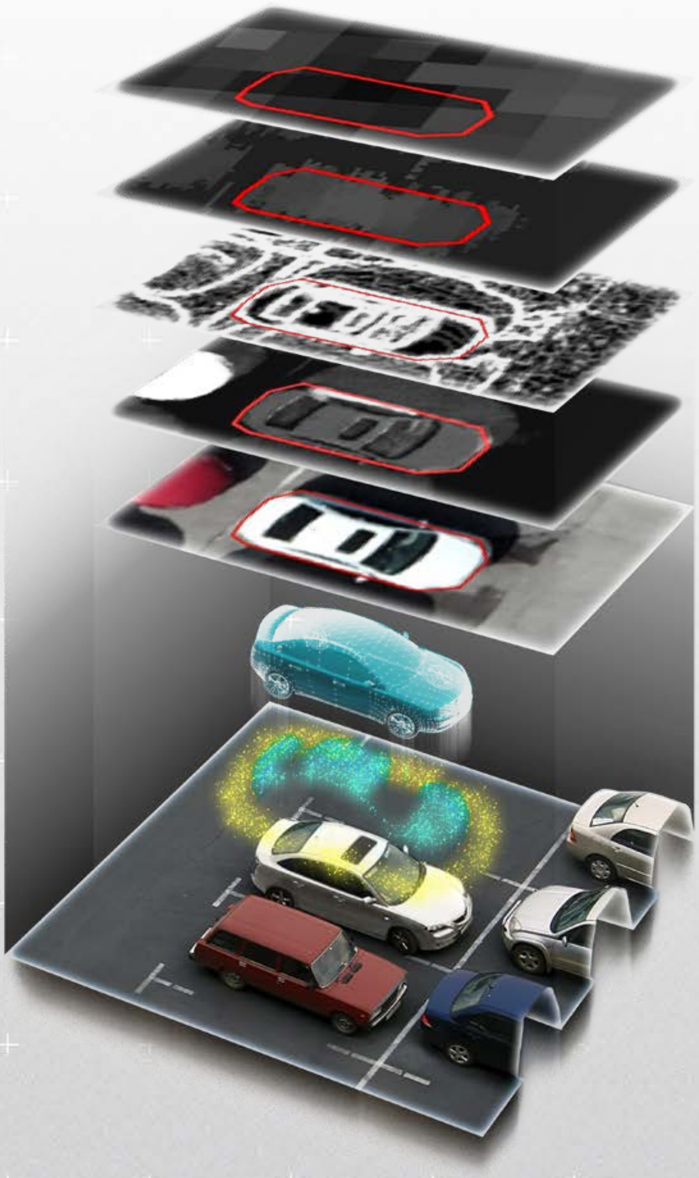
Many of today's state-of-the-art machine learning algorithms and analytics suffer from lack of interpretability and transferability from general applications into niche DoD and intelligence community (IC) use cases. We are experts in developing metrics and evaluation workflows to quantify the performance of machine learning analytics in a way that is meaningful.

This facilitates metrics-driven research, development, and acquisition of state-of-the-art analytics technology.

METRICS AND EVALUATIONS

Quantifying success without the influence of bias is often difficult, particularly when reviewing across multiple phenomenologies and scenarios. As a trusted government agent, ARL has expertise evaluating technologies produced by the community and developing standard datasets and metrics to measure their utility across the range of intended use cases. The Data Characterization Framework (DCF) is a particularly novel metric, inspired by the incompleteness of National Imagery Interpretability Rating Scale (NIIRS) to fully support spectral targets, temporal collection scenarios, and model driven collection.

This physics-based approach probabilistically determines the best sensor product or products to be applied to an intelligence need and provides a metric to assist with the tasking recommendation of commercial and national assets.



A prototype for detecting and characterizing vehicles demonstrates the value of analyzing granular change with interactive visualization.

NON-PROPRIETARY RESEARCH AND DEVELOPMENT

As a UARC for the U.S. Government, ARL provides non-proprietary GEOINT tools, code, and research to our sponsors. Our government sponsors designate the final form factor for the R&D activities we conduct.

This includes: code delivery to open source repositories and IC only repositories, integration, collaboration with integration partners, prototype demonstrations, publications, and direct delivery to the customer.

LEVERAGING OPEN SOURCE, STATE-OF-THE-ART, AND STATE OF PRACTICE

ARL has the ability to take any published algorithm or open source and get a test implementation up and running quickly. With the volume and rate of new algorithms, techniques, and open source being published every day, rapid prototyping and testing are critical capabilities for informative survey activity. We have a diverse team with a robust skill set that spans from literature review to testable prototype, arming decision makers with the information they need to select and apply state-of-the-art solutions.

We champion frequent interaction with end users, the discovery and use of multiple data sources, and maximally leveraging prior work where applicable.

Open Source, State-of-the-Art, State-of-Practice

EFFICIENTLY CONDUCTING APPLIED RESEARCH AND DEVELOPMENT

ARL helps direct and apply R&D across all domains and sciences. We understand that every applied problem has both technical and tradecraft aspects that must be considered when determining a viable solution. We champion frequent interaction with end users, the discovery and use of multiple data sources, and maximally leveraging prior work where applicable.

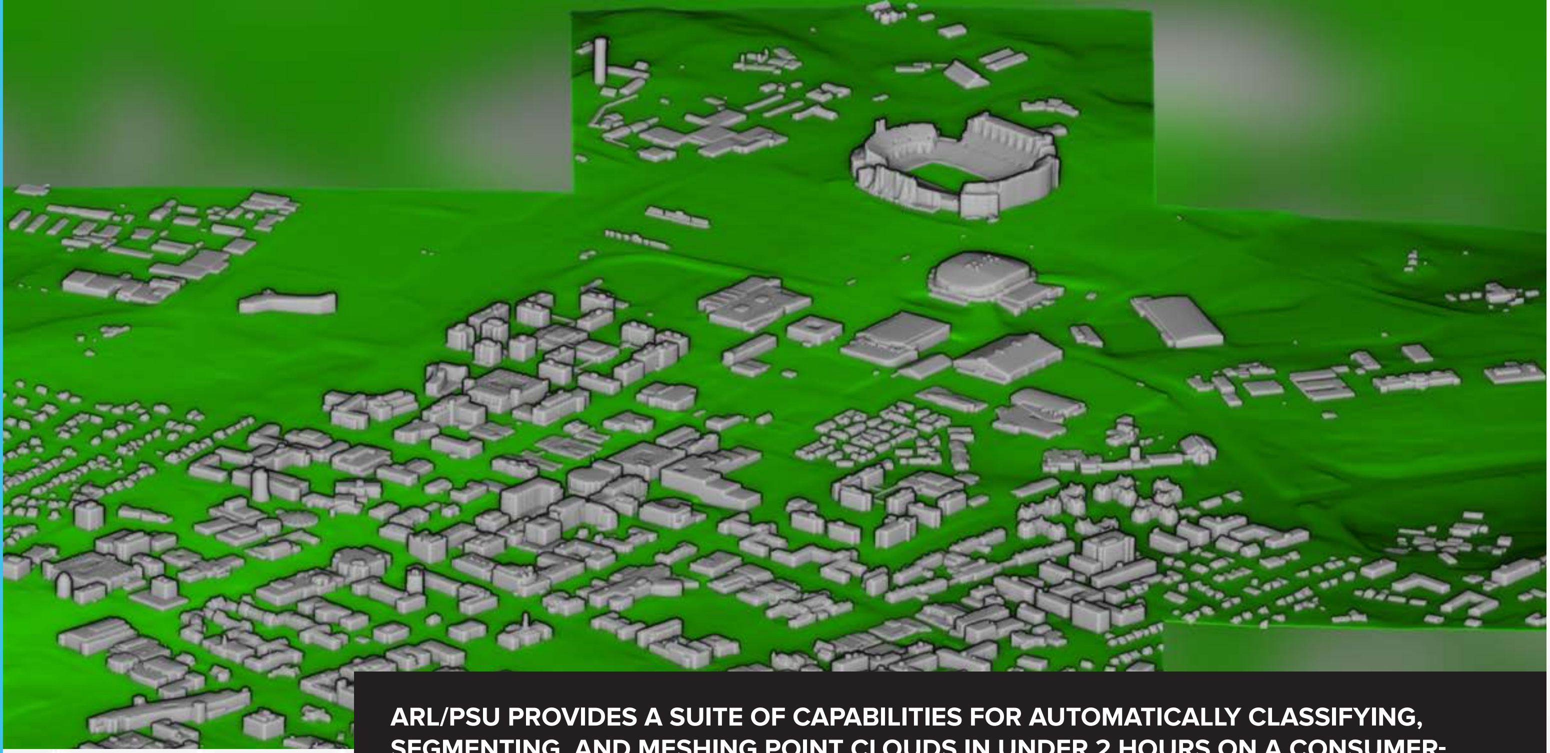
This guides the R&D process toward solving the right problems for the intended users.

SIMULATION AND MODELING

Replicating data sets and obtaining perfect ground truth in real data is rare and can be impossible in large cases. Utilizing simulated data can be very useful when seeking to test collection scenarios or exploitation algorithms. Simulation offers a best-case scenario that can showcase the weaknesses of an algorithm implementation and help to provide a baseline from which to build. ARL has experience building and using many simulation packages with particular proficiencies in DIRSIG.

The data generated has been used to validate collection strategies, train neural networks on rare targets, and assist with the design and implementation of exploitation algorithms on 2D and 3D datasets.

ARL has experience building and using many simulation packages with particular proficiencies in DIRSIG.



ARL/PSU PROVIDES A SUITE OF CAPABILITIES FOR AUTOMATICALLY CLASSIFYING, SEGMENTING, AND MESHING POINT CLOUDS IN UNDER 2 HOURS ON A CONSUMER-GRADE COMPUTER, WITHOUT THE NEED FOR MANUAL OPERATIONS.

FAST, AUTOMATIC CONVERSION OF POINT CLOUD DATA INTO ACCURATE, SEGMENTED MESHES

Raw point clouds provide valuable 3D information, but cannot be directly rendered in most 3D game engines or simulation environments. Traditional manual methods for converting point clouds to more useful formats such as a segmented mesh are incredibly time consuming and limit the ability to exploit these valuable data.

FULL AUTOMATION

Select your point cloud data files, hit the go button, and get the above result in less than 2 hours on a consumer-grade computer.

WORKFLOW FLEXIBILITY

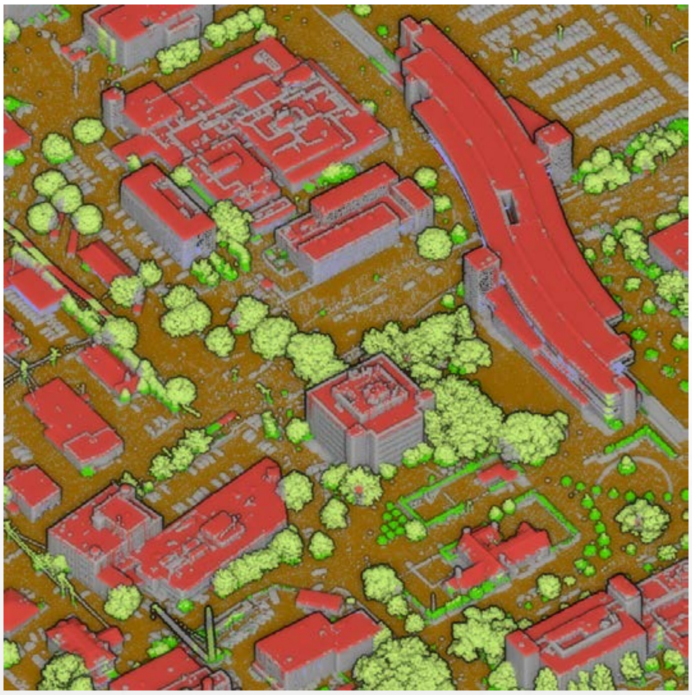
Each capability is implemented as a modular stage in the Point Data Abstraction Library (PDAL). This allows users to create custom workflows to meet their needs and to mix ARL/PSU modules with other custom point cloud processing capabilities.

INTELLIGENT COMPRESSION

The above mesh is **less than 1% of the size of the corresponding building and terrain point cloud** (32.1 MB vs 3.8 GB). These meshes accurately reflect the original geometry up to a user-configurable tolerance, and open the possibility for lower-bandwidth mesh transmission/sharing.

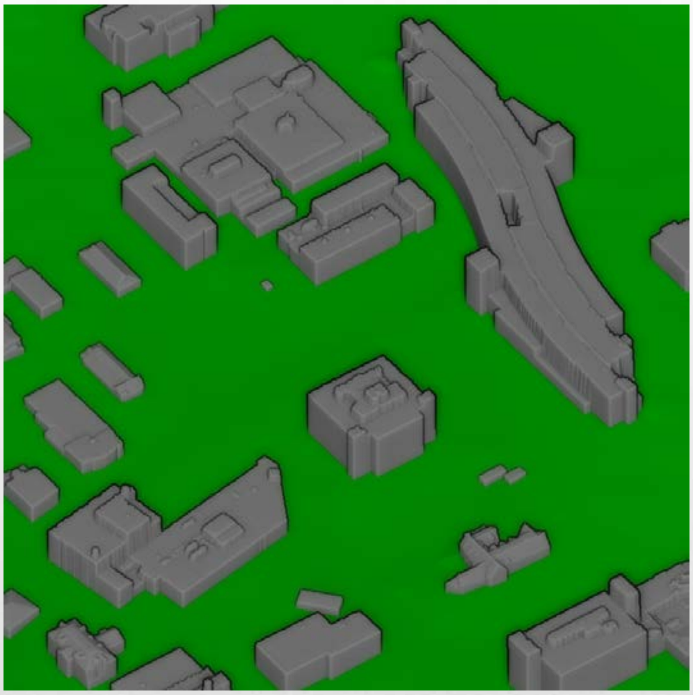
ARL/PSU provides novel mesh simplification that:

- Produces the smallest mesh possible that is within a user-specified error tolerances
  - Accuracy Tolerance — vertices in the simplified mesh must be near the surface of the original mesh
  - Shape Tolerance — faces in the simplified mesh must have an orientation that is similar to their orientation in the original mesh
- Preserves the 2D shape of the outer contour of the mesh



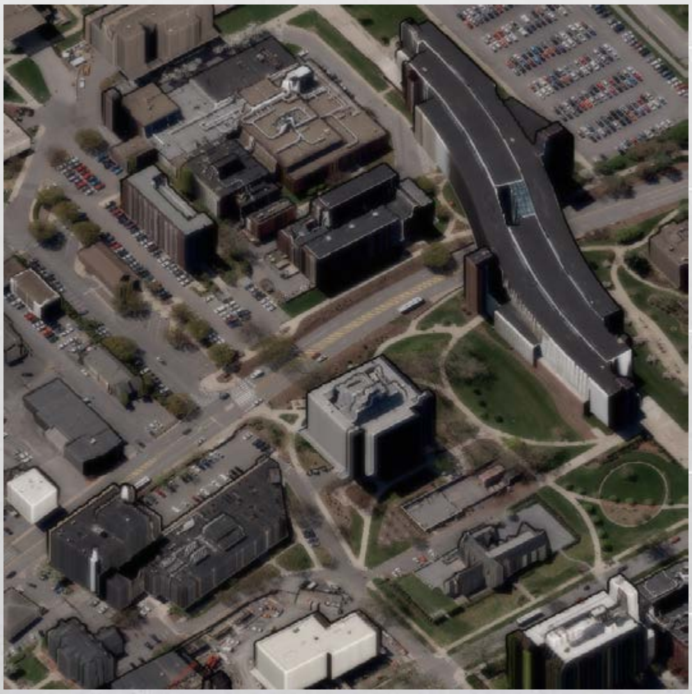
LABELED POINT CLOUD

- Never Labeled
- Unassigned
- Ground
- Low Vegetation
- Medium Vegetation
- High Vegetation
- Building
- Noise
- High Noise



BUILDING AND TERRAIN MESHES

- Building points are segmented into building contours
- A high resolution mesh is draped over each building roof
- High resolution mesh is simplified to within a configurable error tolerance while preserving the building contour
- Walls are added around the building contour



TEXTURED MESH

- In this example an overhead image was simply draped over the mesh.
- Even better results can be obtained with orthorectified imagery and by texturing the walls separately to avoid streaking of the roof texture down the side of the building.

OUR FACILITIES

ARL RESTON

1850 CENTENNIAL PARK DRIVE
RESTON, VA 20191

This facility is host to critical projects for DARPA and other sponsors and supports approximately 100 personnel.

ARL WARMINSTER

300 EAST BRISTOL ROAD
WARMINSTER, PA 18974

This facility was inherited from the U.S. Navy and supports all of CINO's testing of inertial navigation systems.

VISUALIZATION LAB

N. BARNARD STREET
STATE COLLEGE, PA 16804

The Synthetic Environment Applications (SEA) Laboratory is a multi-use test bed facility providing various users access to advanced visualization, simulation and collaboration technologies. This facility hosts the ability to design and test various applications of AR and VR.

RF ANECHOIC CHAMBER

WARMINSTER, PA 18974

This chamber — one of the largest of its type in the country — has enabled CINO to study electronic emissions of various types of sponsor vehicles and platforms.

ROCK SPRINGS RADAR RANGE

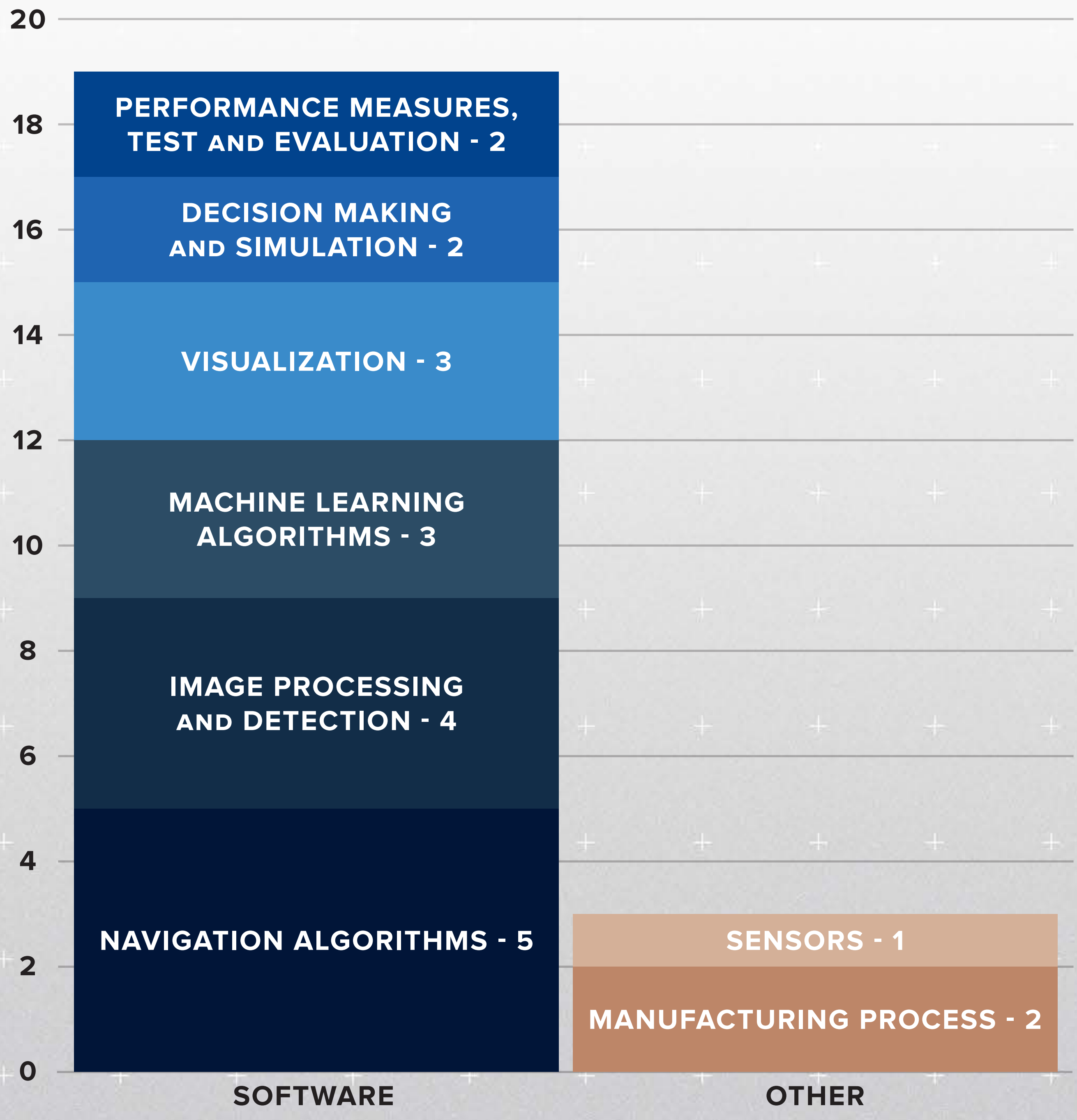
STATE COLLEGE, PA 16803

This outdoor and indoor facility includes an expanse of land that supports studies of effectiveness of various types of ground radars.

INNOVATION AT ARL

Discovery and innovation, two of our guiding principles, drive our desire to explore new areas of research.

As new opportunities in technology, manufacturing, and science arise, ARL remains committed to harnessing these capabilities in support of our mission. Rather than be content to operate in the same areas we've always inhabited, we recognize that attacking technical and programmatic adjacencies, expanding our technology base, and identifying new opportunities are key drivers for continued relevance.



CINO invention disclosures by category since September 2020


ACUTRONIC

SELECTED ARTICLES

Virtual Reality to the USMA: WPSC's Partnership with Penn State's ARL

By Keith J. Hamel, WPAOG staff – this article is reprinted with permission.

The best partnerships evolve. Such is the case with the partnership between the West Point Simulation Center (WPSC) and the Pennsylvania State University Applied Research Laboratory (ARL). The relationship between WPSC and ARL goes back more than five years to when ARL constructed West Point's CAVE Automatic Virtual Environment (CAVE) at a Department of Defense facility and moved it to WPSC through a donation from Bob Acevedo '75. Since then, ARL has been supporting WPSC's visualization efforts, and it is because of this ongoing relationship that ARL got WPSC and West Point cadets involved with supporting the Thunderstorm Technology Demonstration Program.

Operating under the Rapid Reaction Technology Office (RRTO) from the Office of the Secretary of Defense, Thunderstorm is an opportunity to inform and accelerate modernization through innovative discovery, demonstration, and experimentation. "The Thunderstorm Program has been going on for more than 10 years, and Penn State's Applied Research Lab has been involved from day one," says Dr. Vaughn Whisker, the head of the Visualization Technology Department at ARL in CINO. According to a request for information paper regarding Thunderstorm 22-1, "Thunderstorm provides an opportunity for technology developers to demonstrate and experiment with new and evolving technological capabilities in an operationally relevant environment, as well as to obtain insight into federal technology gaps and emerging needs." "We've seen counter-narcotics measures in Key West, Florida; border security initiatives along the Southwest border in Texas and Arizona; counter unmanned aircraft systems; technology discovery for Special Ops; see-through-walls technology and more—all as part of the Thunderstorm Program," says Whisker. In recent years, Thunderstorm, which is open to a wide range of approved participants (mostly small business), has demonstrated approximately 75 new technologies per year.

In 2019, ARL asked WPSC if the Academy would be interested in hosting a Thunderstorm event. "West Point is a fantastic venue for Thunderstorm," says Whisker. "Vendors can interact with cadets who, as commissioned second lieutenants, are the end users of this technology when it is fielded in a few short years." Preparations began, and although plans were disrupted by COVID-19 restrictions, WPSC and ARL virtually presented Thunderstorm 21-1, "Virtual Reality Tools in Support of Enhancing Small Unit Lethality," during the second week of October 2020. Over the course of five days, nine vendors selected by RRTO showcased their wares to cadets, USMA faculty, and invited government POCs, with several of the vendors sending demo devices so that participants could experience the technology firsthand.

For each Thunderstorm event, RRTO solicits participation from companies to solve DoD problem sets. In the case of the 2020 West Point Thunderstorm, RRTO wanted to see how virtual reality technologies could be incorporated into small unit tactics on the battlefield. “Specifically, last year’s event looked at technologies that could collect data on West Point’s Aachen training area, process that data, and then render the building’s environment as virtual reality in a matter of days, versus weeks or months,” says Lieutenant Colonel Chris Johnes, Director of the West Point Simulation Center. Upon receiving the virtual model from the vendor, cadets from the Future Applied Systems Team got to train on the 3-D VR simulation of the target building in WPSC’s CAVE before executing a live tactical exercise. The after-action report for the exercise noted that the simulation allowed the team to walk through the building model together and rehearse how its members wanted to secure it, including their approach from the wood line and the path each member of the team would take through the building.

Thunderstorm 21-1 was a great success, and planning was soon underway for another Thunderstorm exercise at West Point in early October 2021. In December 2020, ARL and WPSC started having discussions regarding what Thunderstorm 22-1 would look like, settling on the theme “Modernizing Combat Planning and Operations by Leveraging Artificial Intelligence/ Machine Learning Enabled Extended Reality Technologies.” There was an initial planning conference in April, a mid-planning conference in June, and a final planning conference in August. According to Johnes, “By our mid-planning conference we knew who our vendors were, and we started to discuss what scenarios we want to execute in a live environment, such as training vignettes.” With this information confirmed, Johnes and his team began planning all the logistics needed to execute DThunderstorm 22-1, such as securing facilities and ranges, and they started pushing out information across USMA academic departments to let interested parties know which vendors were coming to West Point to demonstrate products. “Knowing the theme of the exercise and what vendors and types of products are involved, departments could identify what cadets and faculty members might be interested in attending, with perhaps the intent of using the demonstrated technology in a capstone related research project,” says Johnes.

Thunderstorm 22-1 provided an opportunity for cadets from different academic departments to use technology that could be related to their capstone research projects.

According to Whisker, the West Point Thunderstorm exercise is a win-win for both demonstrators and cadets. “Vendors love it because cadets provide valuable feedback on the relevance and quality of the demonstrated products,” he says. Vendors incorporate such feedback into improving their product or improving the use of their product in an operationally relevant environment, as most vendors do not have access to the kinds of ranges available at West Point or to the end-users of their product. "Cadets enjoy Thunderstorm because they get exposure to modern technologies," says Whisker, "helping them understand what is the art of the possible, so when they are commissioned and out leading in the field they have had exposure and understand how to leverage these products that, for all intents and purposes, are science fiction brought to reality." In other words, Thunderstorm shows cadets today what the battlefield is going to look like tomorrow.

The partnership between ARL and WPSC is also a win-win for both parties. "For ARL, it is rewarding to see the future of DoD in West Point cadets," says Whisker. "Observing how cadets interact with the products demonstrated during Thunderstorm helps us see which innovative technology is worth pursuing from a user perspective." For WPSC, which is a Margin of Excellence developmental program, the team at ARL has proved invaluable as the Simulation Center continues to make improvements to the CAVE and looks forward to the technological advancements in store for Bradley Barracks in three to five years. Says Johnes, "We lean heavily on ARL's expertise and look forward to continuing our partnership with them for the foreseeable future, especially as we start to discuss what could be the next evolution of our partnership beyond the Thunderstorm exercise."

Caption: The Penn State Applied Research Lab constructed the West Point Simulation Center's CAVE Automatic Virtual Environment, a gift from Bob Acevado.

Data Analytics Applied to COVID-19: Race, Employment and an Exploration of Fatality Rate Variance

Christopher Griffin[1], Ray Block Jr.[2], Justin D. Silverman[3], Jason Croad[4], Robert P. Lennon[4]

Abstract

We derive a simple asymptotic approximation for the long-run case fatality rate of COVID-19 (alpha and delta variants) and show that these estimations are highly correlated to the interaction between US State median age and US unemployment rate (Adj. r^2=52%). We contrast this to the high level of correlation between point estimates of per state case fatality rates and the interaction of median age, population density and current unemployment rates (Adj. r^2=53.2%). To determine whether this is caused by a race effect, we then analyze unemployment, race, median age and population density across US states and show that adding the interaction of African American population and unemployment explains 60% of the variance in COVID case fatality rates for the alpha and delta variants when considering instantaneous case fatality rate. Interestingly, when the asymptotic case fatality rate is used, the dependence on the African American population disappears, which is consistent with the fact that in the long-run COVID does not discriminate on race, but may discriminate on access to medical care which is highly correlated to employment in the US. The results provide further evidence of the impact inequality can have on case fatality rates in COVID-19 and the impact complex social, health and economic factors can have on patient survival.

Introduction

The dynamics of COVID-19 have been extensively studied since the beginning of the pandemic.[5] As with many natural systems, the dynamics of COVID-19 are complex with non-linear second order and higher effects playing a role in the dynamics of transmission and fatality.[6,7,8,9] In particular, factors such as age, race, population density, socioeconomic status, and income inequality are all associated with COVID-19 mortality.[10,11,12,13,14] Unemployment alone was negatively associated with morbidity in the first wave of the 1918-19 Spanish Flu pandemic,[15] but with a few exceptions has not been thoroughly explored in this manner for COVID-19.[16,17,18]

In this paper, we show evidence that unemployment is correlated with case fatality rate (CFR) when taking median age into consideration, which partially contradicts results in.[19] We explain this contradiction by the fact that we are using bulk US state-level data, while Sen-Crowe, et al (2021) uses zip-code level data which is known to have substantially more noise in measurement. We also address the question of whether these correlations are caused by the known higher COVID-19 mortality rates of racial minorities in the US and show that by incorporating this data we can explain 60% of the variance in case fatality rates. We also construct an asymptotic estimate for the (true) case fatality rate and show that this is correlated to an interaction between age and projected unemployment. This is important since both CFR and unemployment rate are transient measures. Interestingly, when the asymptotic estimates are used, the dependence on race disappears (as it should) suggesting that COVID does not discriminate on race, but may discriminate on access to medical care which is highly correlated to employment in the US.

A rich scholarly tradition—one that spans the writings of Anna Julia Cooper[20,21] and W. E. B. Du Bois[22] to the more recent research of C. L. R. James[23] William Julius Wilson[24] and Sandy Darity[25]—teaches us that an appreciation for the interconnections between race and class is foundational to the study of social inequality. It is therefore impossible for theoretically-grounded and empirically-rigorous research on "racial disparities" in health outcomes to ignore the role of class divisions.[26] We join the growing body of disparities scholarship by exploring the race/class association as it pertains to the coronavirus pandemic.[27,28,29,30] Specifically, we investigate the role that race and class play in explaining variations in COVID-19 fatality rates.

The main results of this paper are:

1. We derive a simple asymptotic approximation for the long-run case fatality rate of COVID-19 (alpha and delta variants).
2. We show that these estimations are highly correlated to the interaction between US State median age and US unemployment rate (Adj. r^2=52%).
3. We contrast this to the high level of correlation between point estimates of per state case fatality rates and the interaction of median age, population density and current unemployment rates (Adj. r^2=53.2%).
4. We show that incorporating race into the above models explains a full 60% of the variance in COVID case fatality rates for the alpha and delta variants when considering instantaneous case fatality rate. However, the dependence on race disappears when considering asymptotic projections of unemployment and CFR.

Materials and methods

We approach the problem of modeling case fatality ratio (CFR) using an asymptotic analysis of an underlying *SIRD* model, which is not explicitly calculated. Analysis is then carried out over data from the fifty US States. Standard epidemiologic compartment models show that over the course of a pandemic, the case fatality ratio decreases over time to a limiting value. Consider a compartmented epidemic model (e.g., an SIRD model). Let *I* be the instantaneous infected population and *D* be the deceased population. Further let *C* be the instantaneous cumulative case load. In an SI model, $C \equiv I$. Assuming a constant population size then linearizing about the current state of the compartmented epidemic model, we may assume linearized solutions of the form:

$$C \sim C_\infty - \kappa e^{-\alpha(t-t^*)}$$

$$D \sim D_\infty - \delta e^{-\beta(t-t^*)}.$$

The simplicity of the solutions lies in the underlying linearization of the nonlinear SIRD dynamics and allows the derivation of a statistical model to be fit. The model for case fatality ratio is then:

$$r \sim \frac{1+Be^{\beta(t-t^*)}}{K+Ae^{-\alpha(t-t^*)}} + \varepsilon, \qquad (1)$$

where ε~N(0,σ) is a noise variable accounting for experimental error. (Starting from an SIR model would create a more complex form for these expressions. Since it's unclear whether COVID-19 caseload is following any simple SIR dynamic, we use the more parsimonious model.) In the case of COVID-19, the measured caseload is believed to be a fraction of the true caseload. That is:

$$C_{True} = \tau C$$

As $t \to \infty$, we may assume τ is relatively stable (constant) and thus the approximated case fatality rate is too large by a factor of τ.

Using this approach, we can determine a long-run measured case fatality rate:

$$r_{\infty} \to \frac{1}{K}.$$

The choice of t^* in eqn:MainModel is open. By varying t^* over a number of possibilities and varying the size of the data tail we choose, we can construct a family (ensemble) of models following eqn:MainModel and use (i) the distribution on the computed r_{∞} to create upper and lower bounds on the estimator and (ii) use the various models to construct upper and lower bound predictors on the future behavior of CFR. For this study, we varied t^* from 150 (days from January 22, 2020) to 330 (days from January 22, 2020) in increments of 10 days. The tail of the data used to fit eqn:MainModel started at day t^* and proceeded to day 430, the last day of the data sample used.

Predicting the final CFR from early data is challenging, as there are confounding variables that may cause the model to over- or underestimate the true CFR.[31] For example, early models of COVID-19 did not account for the very high number of undiagnosed persons with COVID-19, leading to significant over-estimation of CFR. Further, different states may be at different points in the epidemic, leading to variances between states in CFR estimates. However, regardless of the ultimate CFR, the limiting behavior of CFR remains useful in analyzing factors that contribute to COVID-19 fatalities, because while different states may be at different places in their epidemic, the limiting behaviors should be invariant if we make two assumptions.

Case Fatality Rate Modeling

In comparing CFRs between states, it is reasonable to ignore the effects of the undiagnosed over short time frames, because the population percentage of undiagnosed can be considered constant over recent history. Analysis of variations in states' CFR supports this. To compute instantaneous case fatality rate, we use data from Johns Hopkins COVID Dashboard (`https://github.com/CSSEGISandData/COVID-19`) from April 8, 2021. We then compare forecasts to data from October, 2020 and December 2020. We use these dates because after this time, vaccination was widely underway in the US and the less severe Omicron variant would be responsible for further waves, thus distorting the underlying data on the alpha and delta variants.[32]

At time *t*, the instantaneous case fatality rate was computed as:

$$rnow = \frac{D_t}{I_{t-14}},$$

where D_t is the total number of deaths in a given state by time *t* and I_{t-15} is the total number of cases in that state at time assuming that recovery or death occurs within 14 days of diagnosis. Examining individual state case fatality rates shows substantial variation.

Fig. 1 shows case fatality rates for 6 randomly selected states representing different regions of the country along with the fits of eqn:MainModel.

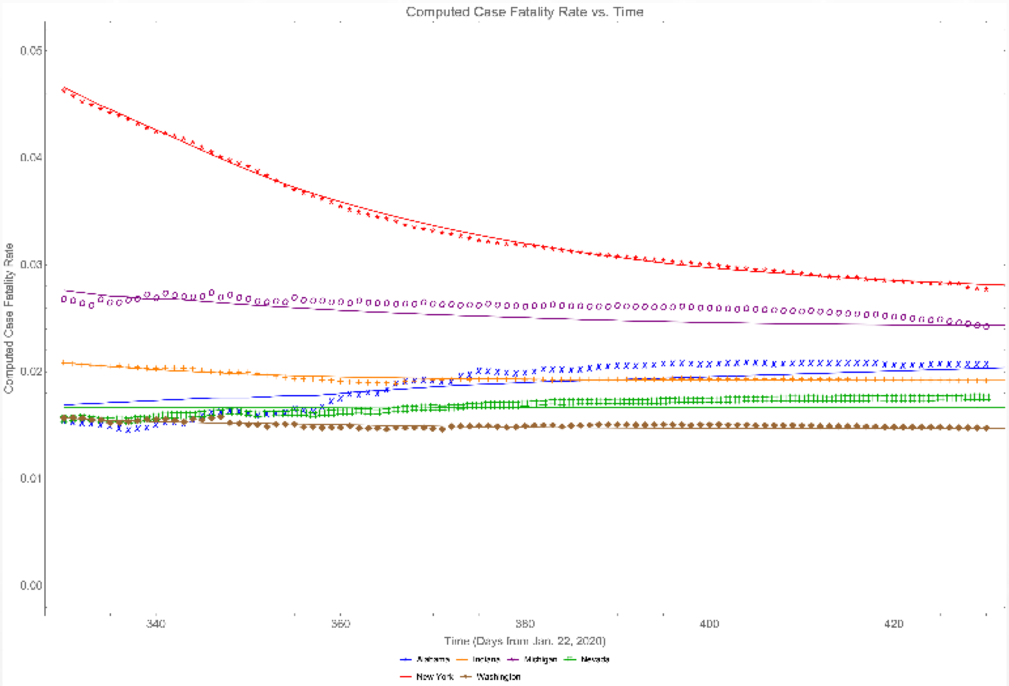


Figure 1: Asymptotic behavior of case fatality rates for various states.

We also assume that τ is related to the proportion of the population tested, denoted *p*, within each state. Here:

$$p = \frac{\#test}{statepopulation}.$$

To assess the possibility that τ is not consistent across states, we regress *rnow* against *p*. This is shown in Fig 2.

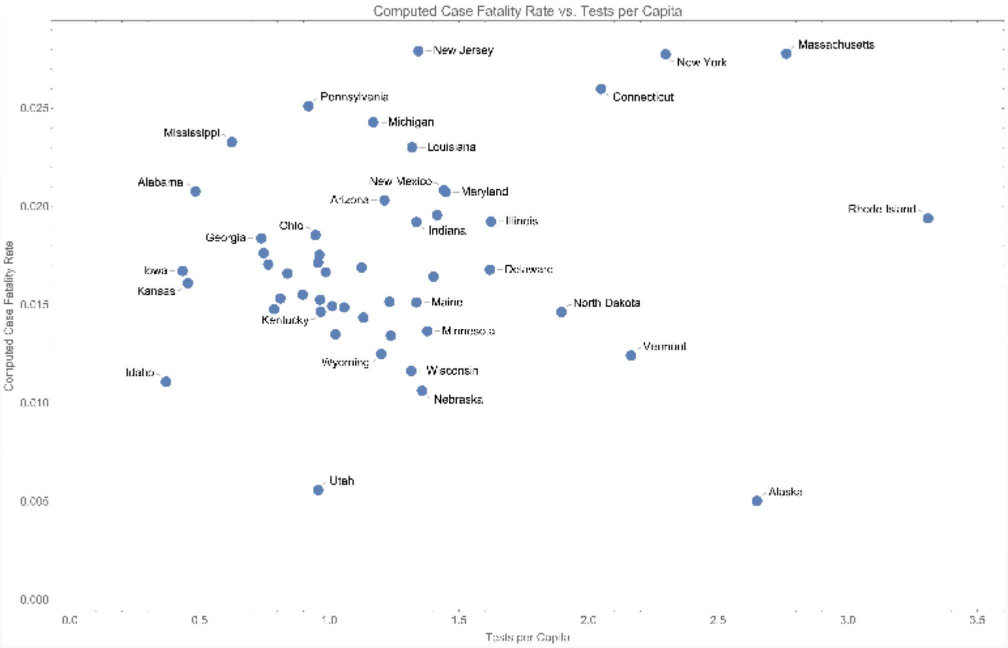


Figure 2: Comparison of the instantaneous case fatality rate and proportion of people tested in each state shows no correlation.

There is not significant correlation between the per-capita testing and instantaneous (computed) CFR, suggesting that at the point the data were taken, τ should be constant across all states. As we will see, this will support our hypothesis that variance among CFR (and asymptotic CFR) is explained by external social factors like unemployment and minority proportion.

It is also possible to use the per-state asymptotic CFR to estimate the asymptotic US CFR assuming that as $t \to \infty$ the entire population will be exposed to COVID19 and considering a no-vaccine scenario. We use the weighted average:

$$rUS_{\infty} = \frac{1}{P} \sum_{s} P^{s} r_{\infty}^{s},$$

where P is the total US population, P^s is the population of state s and r_{∞}^{s} is the asymptotic CFR of state s. Using this we obtain a 100% orders-statistic confidence interval on the CFR of (0.008,0.019) with a pointwise estimator of 0.016. This is consistent with the single fit of cumulative US data, which estimates a nation-wide CFR of 0.0184, which is on the high-end of the confidence region. This is illustrated in Fig 3.

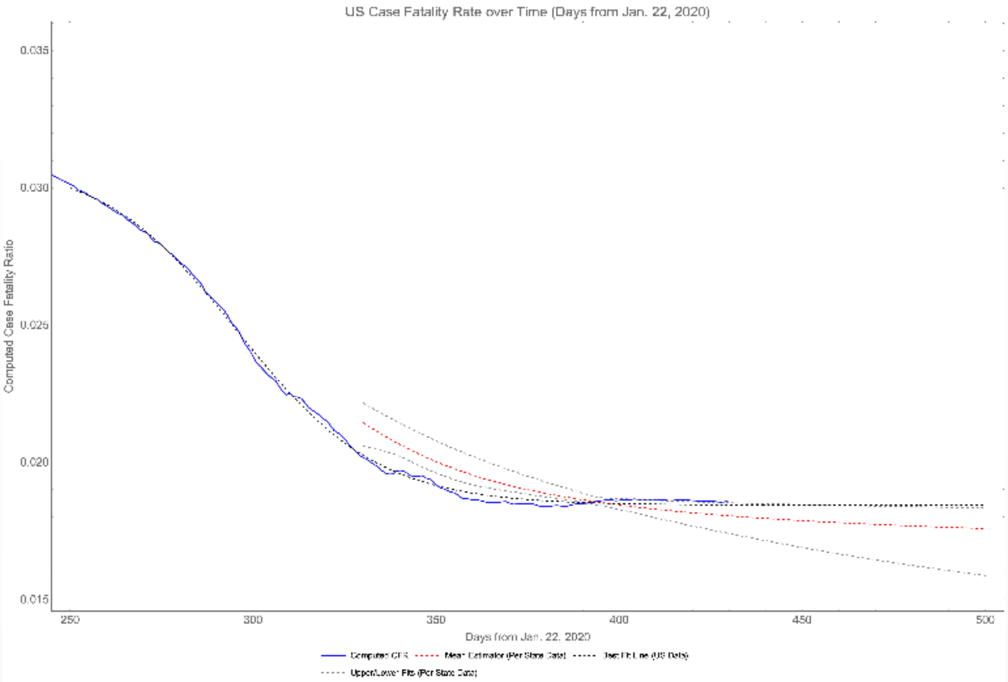


Figure 3: Case fatality rate for the US as a whole through April 2021 with various multiples.

Verity et al., estimate the true 95% confidence interval on CFR as (0.0039,0.0133).[33] Comparing our CI with theirs, we see there is statistical agreement in the two approaches. Using Verity et al.'s model, we can estimate the under-sampling rate τ for the whole U.S. is contained in the interval (1.40,4.76), which is consistent with past estimates.

Using the correction to r_∞ we can compare the asymptotic case fatality rate to the instantaneous case fatality rate using the data from October 20, 2020. This is shown in Fig 4.

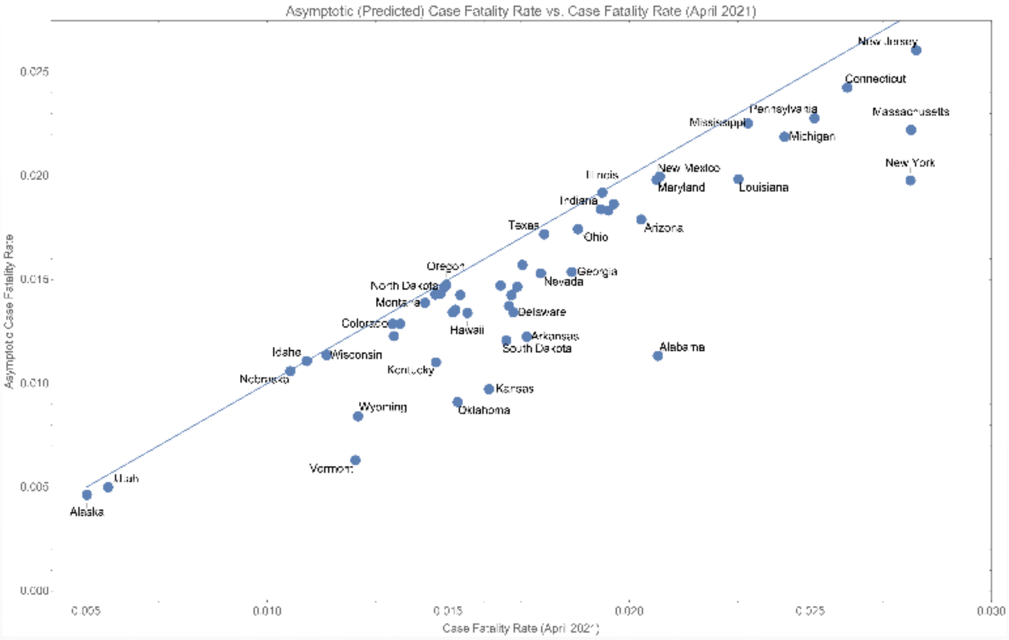


Figure 4: Comparison of the true case fatality rate (ending April 2021) and the projected case fatality rate.

In this data, four states: Alabama, Kansas, Oklahoma, and Vermont, have asymptotic case fatality rates that are more than 1.5 times lower than their current estimated case fatality rate. However, if we apply the correction factors derived above, we see that all of those states may already be explained by unidentified cases. This is shown in Fig. 5 where we show the region in which these states would lie if we correct using the estimate of τ derived for the U.S.

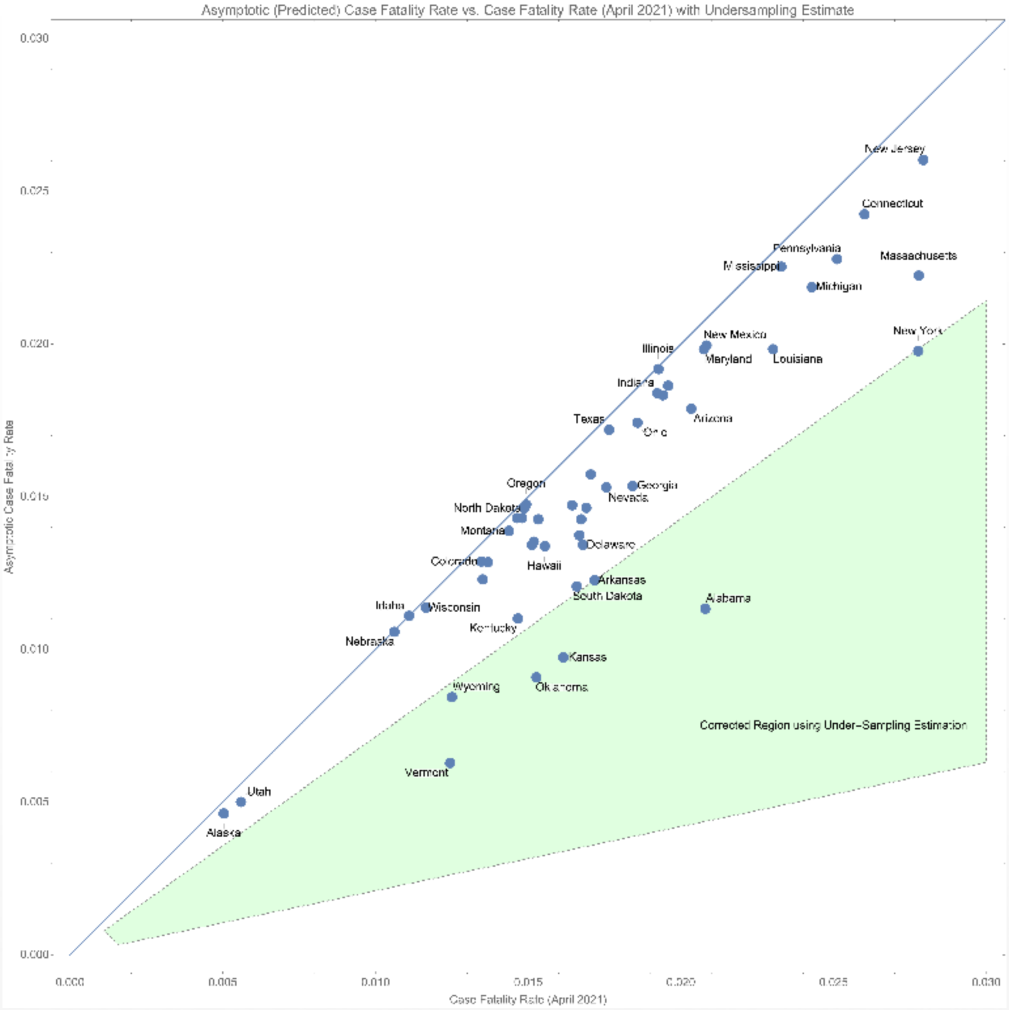


Figure 5: The correction region showing the projection of the case rates forward agrees with the computed correction factor for the four outlier states.

Results

CFR and Unemployment

If we use the instantaneous (computed) case fatality rate over all states, 50.7% of the variance in this variable can be explained by the interaction of three simple variables: current unemployment rate [oLS20] (*u*), population density (*d*) and median age(*a*) with the model:[34]

$$r \sim \gamma a u + \beta \log_{10}(d) + \varepsilon \qquad (2)$$

We use the log of the population because it generally improves adjusted r^2 while simultaneously decreasing AIC. The unemployment rate is provided by the US Dept. of Labor and reflects the unemployment recorded on March, 2021. The parameter table with significance is shown in below.

	Estimate	StandardError	$t-$Statistic	$P-$Value
1	0.0035	0.00198	1.744	0.0876
au	0.00003	8.221×10^{-6}	3.6539	0.00065
$\log(d)$	0.0039	0.0009	4.119	0.00015

On its own, unemployment is correlated with instantaneous case fatality rate (p<0.001) and explains 27.8% of the variance. The model in eqn:StatModel2 along with the correlation of unemployment and instantaneous case fatality rate is shown in Fig. 6.

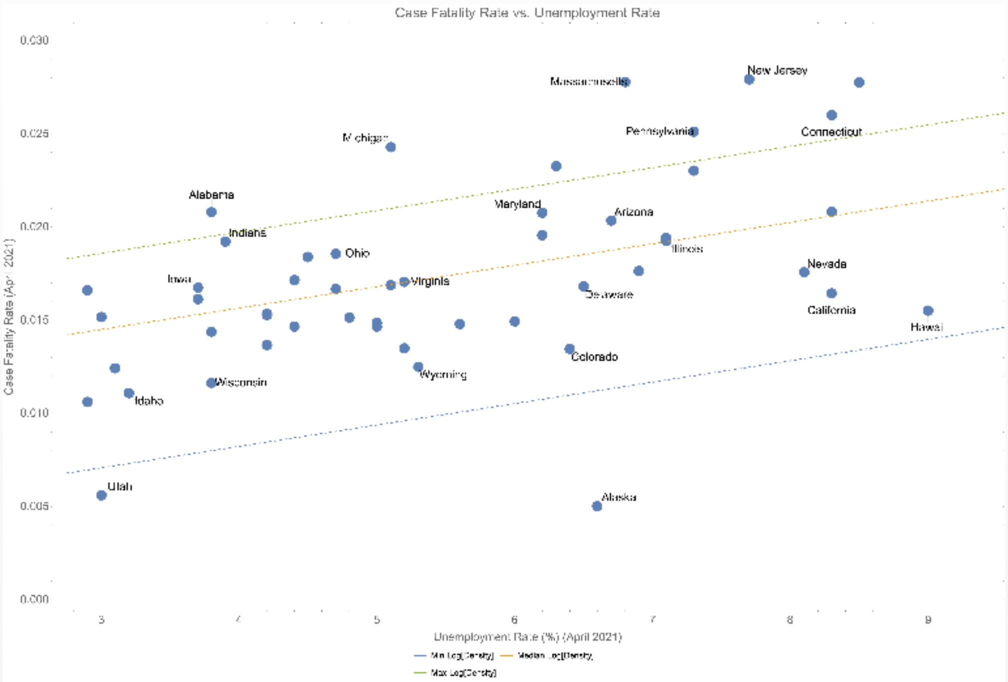


Figure 6: Case fatality rate (April 2021) compared to unemployment rate across states and for various ages.

We tested a model in which we predict unemployment using the inverse of median age, population density and computed case fatality rate. This model explains only 27% (adjusted r^2) of the variance and the population density is not a significant estimator of unemployment as would be expected if eqn:StatModel2 could be used to solve for u. This suggests that we are not just seeing a simple correlation.

Temporal and Asymptotic Analysis

The correlation between unemployment and instantaneous (computed) case fatality rate is consistent over time. If we use monthly unemployment data and the instantaneous CFR computed on (or about) the 20*th* of each month, then we can see that the correlation between instantaneous CFR and monthly unemployment were consistent since May 2020. The Bonferroni corrected p-value for all fits is p=0.0498, showing that all these correlations are significant simultaneously at the 0.05 level. These results suggests a strong correlation between CFR and the existence of a correlation between structural unemployment in a state and its asymptotic CFR.

When the case fatality rates are corrected using asymptotic approximation and we replace r with r_∞ in eqn:StatModel2, then 52% of the variance in r_∞ is explained. However, current unemployment is a transient, while r_∞ is used to measure long-run behavior. Supported by the correlation between instantaneous CFR and monthly unemployment illustrated in tab:SuppTab2 in the SI, we construct an asymptotic projection for unemployment using a power-law:

$$u_t = c + \frac{a}{t^d}.$$

This projection is constrained so that c is not allowed to fall below unemployment from August 2019 [oLS20], which was a point of historically low unemployment. As time goes to infinity, we can compute u_∞. The relationship between unemployment in August 2019 and the projected unemployment is shown in Fig. 7.

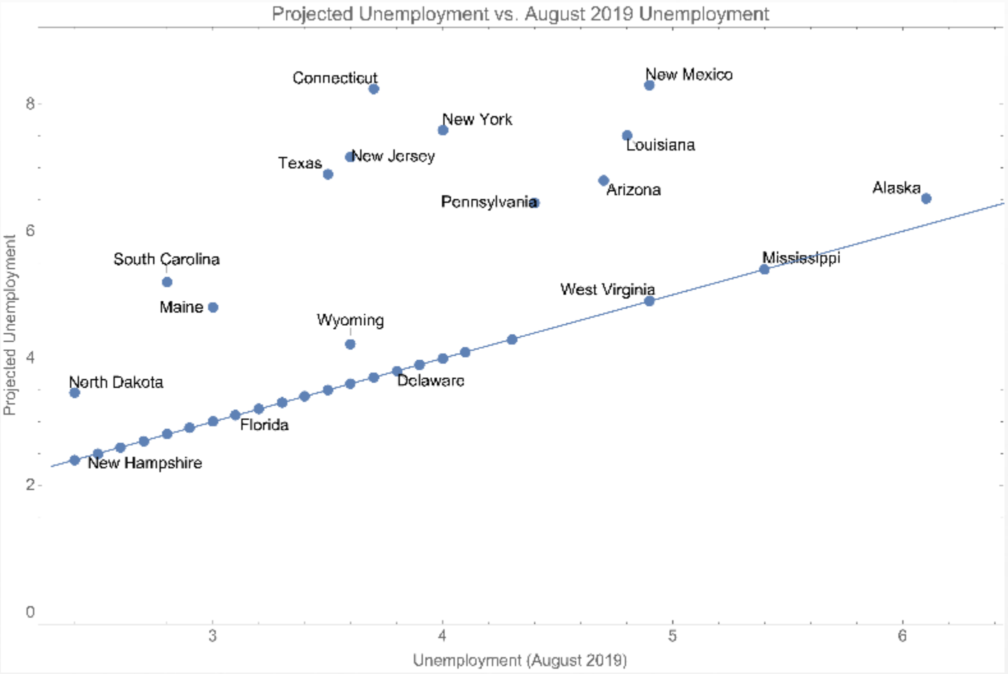


Figure 7: The relationship between projected unemployment and unemployment in August 2019.

Most states were projected to return to their pre-COVID unemployment levels. However, a small set of states may have longer term higher levels of unemployment as a result of COVID.

When we replace *u* in eqn:StatModel2 with u_∞, and adjust eqn:StatModel2 to be:

$$r_\infty \sim \gamma a u_\infty + \beta \log_{10}(d) + \varepsilon,$$

we obtain the fit table:

	Estimate	StandardError	t−Statistic	P−Value
1	0.0004	0.0017	0.2405	0.8110
au_∞	0.00004	6.994×10^{-6}	5.6072	1.0528×10^{-6}
d	0.0043	0.0007	5.76814	6.028×10^{-7}

On its own, the projected unemployment rate explains 27% of the variance in the asymptotic case fatality rate ($p<0.001$) and again illustrates the correlation between case fatality and structural inequality and poverty. When interacting with median age and population density, 60.0% of the variance is explained. These fits are illustrated in Fig. 8.

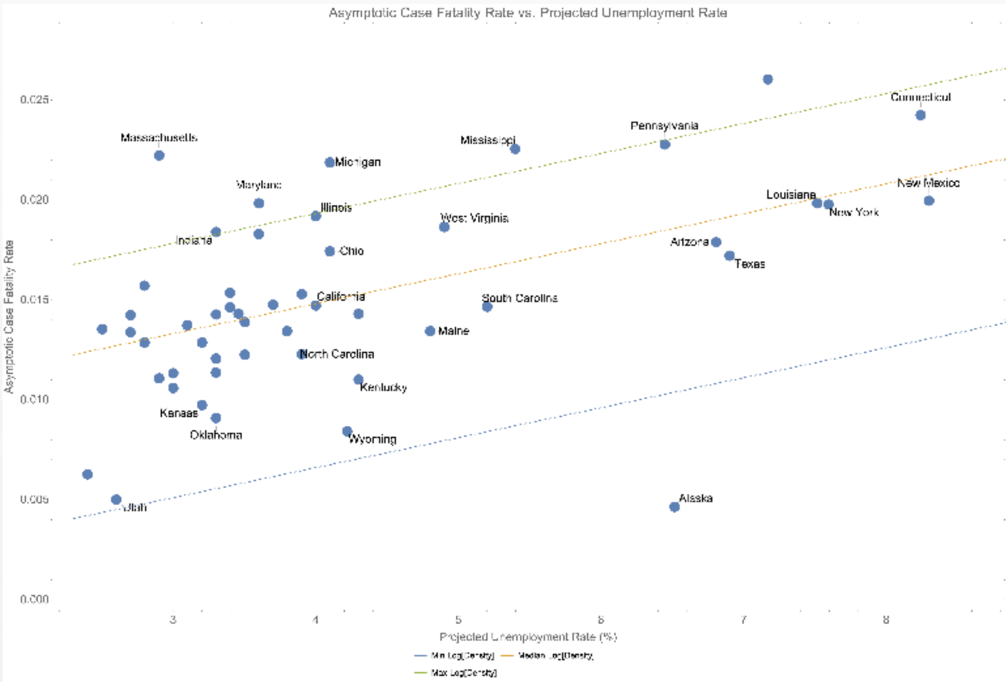


Figure 8: When interacting with median age, asymptotic unemployment explains 60% of the variance in asymptotic case fatality rates.

CFR and Race

There is a known relationship between CFR and minority status, with minority populations bearing the greater brunt of COVID-19. It is therefore reasonable to expect that the relationship between unemployment and instantaneous CFR is a result of the higher rate of unemployment among minorities, which is illustrated in fig:Fig3 in the SI (p<0.001).

We note that the correlation between minority population proportion and August 2019 unemployment is only weak (p=0.056). This will be instructive when we evaluate the role minority status plays in asymptotic CFR. We now evaluate the relationship between minority population proportion and CFR using the simple linear model:

$$r \sim am+b,$$

where m is the minority population proportion and as before r is the CFR. Because there is substantial geographic diversity among minorities in the US, we perform 3 analyses: (i) an analysis of the relationship between minority proportion and instantaneous CFR in all 50 states, (ii) in the lower 48 states and (iii) in states where the population is composed of at most 30% minorities (total). Results of these analyses are shown in Tables 1 – 3.

Table 1: Relationship between minority proportion and instantaneous CFR in all 50 states.

Group	Lin. Coeff.	p-val. of Corr. to CFR
African American	0.0225	0.0017
Latinx American	0.0077	0.2641
Asian American	0.0066	0.6118
Indigenous American	-0.0535	0.0250
Islander American	-0.0471	0.3510
Other American	0.0455	0.0731
Multi-Racial American	-0.02378	0.2858
Non-Caucasian	0.0079	0.0416

Table 2: Relationship between minority proportion and instantaneous CFR in the lower 48 states.

Group	Lin. Coeff.	p-val. of Corr. to CFR
African American	0.0207	0.0031
Latinx American	0.0065	0.3225
Asian American	0.0544	0.0294
Indigenous American	-0.0262	0.3928
Islander American	-1.0203	0.0059
Other American	0.0398	0.1037
Multi-Racial American	-0.0365192	0.5651
Non-Caucasian	0.0107	0.0064

Table 3: Relationship between minority proportion and instantaneous CFR where the population is composed of at most 30% minorities (total).

Group	Lin. Coeff.	p-val. of Corr. to CFR
African American	0.0472	0.0081
Latinx American	-0.0444	0.0586
Asian American	0.0665	0.4461
Indigenous American	-0.0211	0.6116
Islander American	-1.25	0.0065
Other American	-0.1575	0.0454
Multi-Racial American	-0.0707	0.6413
Non-Caucasian	0.0033	0.8126

The proportion of minorities (as a whole) is significantly correlated with instantaneous CFR only in the lower 48 states and the US as a whole. In low-minority states, it is not significantly correlated.

However, the proportion of African Americans is always positively correlated with CFR. The remaining correlations (e.g., the negative correlation between Pacific Islander Americans and instantaneous CFR) are most likely spurious because of small sample size effects.

These results suggest that comparing unemployment and the proportion of African Americans will help determine whether the relationship between unemployment and CFR is a minority population effect. The correlation between current unemployment and the proportion of African Americans in a state is not significantly correlated (p=0.236) nor is the proportion of African Americans in a state significantly correlated to unemployment in August 2019 (p=0.12), when the US was at or above full employment prior to the pandemic. Thus, it is unlikely that relationship between unemployment and CFR is a result of correlation between unemployment and minority proportion. This suggests a combined model.

Combined Model

When we alter eqn:StatModel2 to include an interaction term between the proportion of African Americans in a state and unemployment we have:

$$r \sim \gamma au + \beta \log_{10}(d) + aAu + \varepsilon. \tag{3}$$

Here A is the proportion of African Americans in the state. The resulting model parameters are all significant (see below).

	Estimate	StandardError	t−Statistic	P−Value
1	0.0045	0.00197874	2.263	0.0284
au	0.00004	8.119×10^{-6}	3.2678	0.002
d	0.0032	0.00098	3.15367	0.003
Au	0.0020	0.00096	2.08461	0.043

This model explains 53.9% (Adjusted r^2) of the variation in the data and suggests that unemployment, age, population density and minority status interact in complex ways to increase the instantaneous CFR.

When we consider asymptotic CFR and modifying eqn:StatModel3 as:

$$r_\infty \sim \gamma au_\infty + \beta \log_{10}(d) + aAu_\infty + \varepsilon \tag{4}$$

no terms involving the proportion of African Americans in a state are significant (in eqn:RaceStatModelLim, p=0.485 for the coefficient of $Au\infty$). Even replacing Au_∞ with A is not significant. This is sensible since in the long-run, COVID is not a disease that discriminates on race. It seems to be a disease that discriminates on access to medical care required to treat acute pneumonia that may occur as a result of infection.

Discussion

The correlation between COVID-19 case fatality rate and both race and unemployment is consistent with the prevailing theory that minority disparity in COVID-19 outcomes stems from systemic racial injustice which drives disparity across all sociodemographic covariates.[35] This theory is further corroborated by analysis which has shown that mortality for persons able to access hospital care does not differ between African American and White patients after adjusting for sociodemographic factors and comorbidities,[36] that racial disparities in COVID-19 appear to be driven primarily by unequal infection risks (i.e., sociodemographics) rather than case fatality rates,[37] and that racial segregation explains higher African American mortality to such a degree that no as-yet unmeasured confounder is within the range of plausible covariates.[38,39] Our model is also supported by the current (December 7, 2021) CFR of 0.016 which was our point-wise estimation of CFR from data through March 2021.[40] The pointwise estimator as of March 2022 is 0.012,[41] reflecting improved vaccinations, treatments and the decreased aggressiveness of the Omicron variant.[42] However, this value is still well within our forecast confidence interval. In states with minority populations <30%, case fatality rates remain correlated with unemployment, but not with race. This suggests that unemployment alone is an independent risk factor for COVID-19, and may be considered in evaluating individual and group risk of COVID-19. Further, in populations with lower minority proportions, unemployment is a greater risk factor than race.

It is important that these findings not be misconstrued to suggest that racial inequity does not exist in states with low minority populations. Rather, it should be taken as evidence that race and class are two sides of the same coin.[43]

Conclusion

In this paper we analyzed the interactions of the complex social phenomena of age, race, unemployment, population density and COVID-19 case fatality rate using both pointwise time series data and an asymptotic projection of unemployment and case fatality rate. We showed correlations to non-linear interactions between age, unemployment and age and race to COVID-19 CFR. We also showed that in the limit as time goes to infinity, we expect COVID-19 CFR to uncorrelate to race, which is consistent with the fact that COVID-19 fatality does not discriminate by race but may discriminate by access to medical care, which is predicted by socio-economic status in the US. This work is contrasted with the work in Sen-Crowe, et al (2021), which did not find correlation of CFR to unemployment but analyzed zip-code level data, which may have had higher noise levels in the unemployment rates. Future work should determine whether the observations made here can be translated to zip-code level data and further determine the impact of socio-economic status and race on COVID-19 fatalities.

Unequal outcomes across all aspects of the COVID-19 pandemic have highlighted systemic racial injustice in our society, and are appropriately driving calls for systemic change. The present paper offers data-driven support for such change, but also that unemployment is an independent, persistent risk factor for harm from the COVID-19 pandemic. Achieving equitable healthcare in the U.S. requires overcoming racial and economic disparities.

Supporting information

S1 Fig.

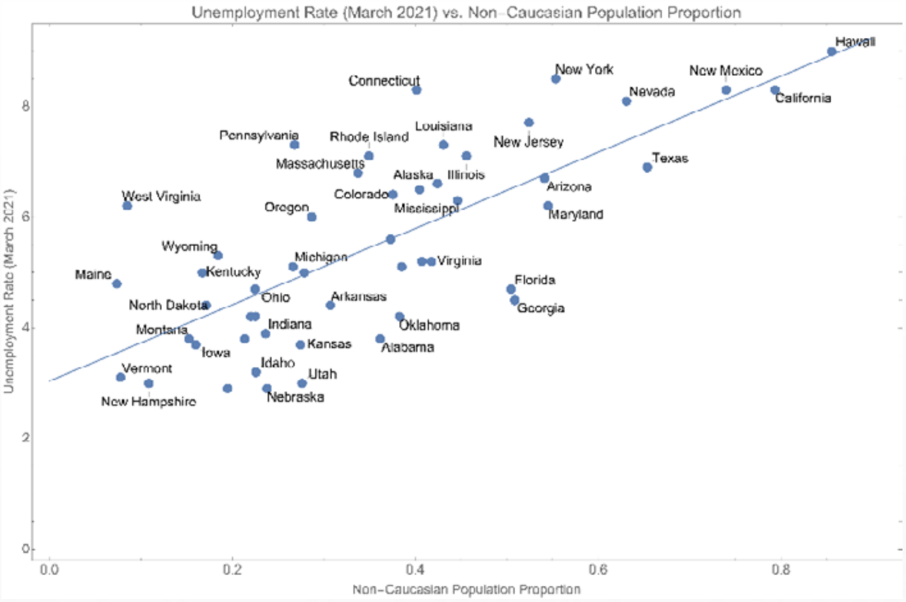


Figure 9: Relationship between current unemployment and minority population proportion.

S1 Table

Table 4: The correlation between CFR and unemployment rate, month-by-month from May 2020 - March 2021.

Mon-Yr	Unemployment vs. CFR Correlation p-Value
May-20	0.0056
Jun-20	0.00056
Jul-20	9.312×10^{-6}
Aug-20	0.0018
Sep-20	0.0032
Oct-20	0.0262
Nov-20	0.0132
Dec-20	0.00002
Jan-21	0.00002
Feb-21	0.00012
Mar-21	0.00004

Quantum Research

Matthew Brandsema, Ph.D., Leslie Ross, Ph.D., Christopher Griffin, Ph.D., Aaron Fleishman

Interest in quantum science has been increasing dramatically in the last few years. This interest has generated many funding opportunities to assist in accelerating progress in the field to maintain US technological advantage. The natural question arising from this circumstance: how can one enter into this field of research to obtain some of this funding, and will this effort be fruitful? Many organizations are posing the same question for themselves and as such, program managers are being inundated with proposals from labs wanting to "get into quantum." It therefore is important to be critical about exactly what area of research is worth investing in, and whether or not there is a true novel contribution to be able to stand out.

The field of quantum science has a steep learning curve. It requires a good knowledge of the theoretical foundation, a topic which differs greatly from classical physics, and to this day still generates debates about how exactly to understand it. Furthermore, many active research areas are quite expensive, in many circumstances requiring over a million dollars of up-front investment. There are however, many avenues into the field of quantum science, each one possessing its own set of challenges and investments. This report provides a very broad overview of a subset of current research topics to help give the reader a cursory sense of what is involved in each topic area in regard to knowledge, techniques, and costs.

Work Performed at ARL

CINO conducts experiments relating to quantum radar and remote sensing, as well as in quantum communications and key distribution. In particular, most research efforts focus on using correlations from entangled photon pairs to perform various tasks. For remote sensing, these correlations are used to ascertain distance on a stand-off target in a stealth-like and spoof-resistant manner. For communications, these correlations are used as a means of detection of tampering or unauthorized access to a secure area or to secure equipment / commodities.

In addition, we are also collaborating with Penn State faculty from several departments/colleges: Electrical Engineering, Engineering Science and Mechanics, and Physics. In general, ARL seeks to collaborate strongly with PSU faculty in a wide array of projects related to quantum science.

For further reading on our efforts, please see the following papers:

- "Correlation properties of single photon binary waveforms used in quantum radar/lidar," MJ Brandsema, RM Narayanan, M Lanzagorta, Radar Sensor Technology XXIV 11408, 114080Q (2020)
- "Equivalence of Classical and Quantum Electromagnetic Scattering in the Far-Field Regime," MJ Brandsema, M Lanzagorta, RM Narayanan, IEEE Aerospace and Electronic Systems Magazine 35 (4), 58-73 (2020)
- "Remote sensing performance enhancement due to quantum+ classical cooperative sensor," BM Ahmed, MJ Brandsema, RA Bowell, RM Narayanan, SW Howell, J. Dilger, Radar Sensor Technology XXIV 11408, 114080R (2020)

- "Electric field correlations in quantum radar and the quantum advantage," RA Bowell, MJ Brandsema, BM Ahmed, RM Narayanan, SW Howell, J. Dilger, Radar Sensor Technology XXIV 11408, 114080S (2020)
- "Tripartite correlation performance for use in quantum radar systems," RA Bowell, MJ Brandsema, RM Narayanan, SW Howell, JM Dilger, Radar Sensor Technology XXV 11742, 117420I (2021)

Quantum Information

Quantum information is the study of how to store, extract and utilize information in quantum states and systems. The field of quantum information is very broad and encompasses many areas of research. Quantum communication uses these concepts to allow secure information transfer between two parties. Quantum computation uses these concepts to perform calculations and algorithms in a manner which is much faster than classical computation. The unique properties of quantum states offer advantages in regards to security and performance. In this section, the focus is on the qubit, or quantum bit; the basic unit of quantum information. Namely, the different ways in which one can construct a qubit, and the equipment necessary to do so. The list is not exhaustive but does include some of the most popular implementations. The following two sections (quantum computing and quantum cryptography / key distribution) rely on the topics discussed here heavily, and therefore one should consider these investment costs as preliminary to the costs outlined in these sections. In classical information, the bit's value is either 0 or 1 and can be realized by the ON or OFF nature of a transistor. In a similar manner, physical realizations of a qubit consist of two-level systems, or quantum systems that have a very high probability of only occupying two possible states. In contrary to the classical bit however, qubits can be in both states simultaneously via a superposition of states. This superposition leads to many interesting and valuable properties such as allowing one to have increased security across a channel (leading to quantum cryptography/comms), and increased correlation performance, and thereby better channel throughput. Qubits can also be used to perform calculations by utilizing these superposition properties (leading to quantum computing).

Qubits can be constructed from photons and their related properties. The advancement of photonic qubits is attractive as one would then be able to perform quantum computing and quantum information related tasks using a single methodology. An advantage to using photons is that they tend to not interact with one another very much at all, thereby being robust to cross-qubit information loss via interaction mechanisms. This advantage is a double edge sword however when one needs to perform operations on the qubit, as it usually requires non-linear interactions, which are difficult to implement. There are linear techniques to manipulate photonic qubits, but they can be limited for certain applications.[44,45] These linear techniques do however appear to be the most common as their simplicity is attractive. Photonic qubits are a difficult medium because they require delay lines or other similar devices to implement quantum memory.[46] When encoding information on a qubit, the qubit cannot be measured in any way and thus must remain untouched until one desires to extract the information. In the space of photons, this means a photon must be able to continue propagating for the time one wants to store the information. Currently, memory storage times are on the order of microseconds.[47] Implementation of these qubits can be done in many different ways. One method is to encode information on a photons polarization, where a 0 and 1 are represented by horizontal and vertical polarization respectively.[48] A second method is to use the photon number state, namely, does a photon exist (1) or does it not exist (0)?[49] In other words, looking at occupied time bins. Finally, one can use squeezed light and encode information on the quadrature states (I and Q).[50,51] To perform these types of experiments, a quantum optics lab is necessary. This includes all of the usual equipment such as an optical bench, posts, clamps, lenses, mirrors etc. Additional equipment is dependent on the type of encoding one chooses to pursue. For all methods, single photon counters and timing electronics are necessary, with the number of counters required being a function of the encoding strategy. For polarization and time bin encoding, it is only necessary to count 1 or 2 photons at a time, thus the maximum number of photon counters is limited to 2. For quadrature encoding, it requires two counters per photon. Thus, the maximum number of counters is 4. For each of these encoding schemes, it is usually the case that one uses the maximum number of counters, as measurements involve pairs of entangled photons, and thus need to count two photons at once. For quadrature encoding, one investigates different quadrature phase offsets by slightly changing the path length of one of the photons. Since the wavelengths are so small, this requires the use of accurate piezoelectric actuators which move a very small amount (on the order of nanometers) for an applied voltage.[52]

Electron Qubits

Electron qubits generally use the electron spin (up or down) to encode data (1 or 0 respectively). The most common implementation is to construct a nano-structure called a quantum dot. A quantum dot consists of electrodes that are very closely spaced and energized or externally biased in a manner to create various potentials to trap or move an electron, or otherwise manipulate its properties.[53,54,55] See Figure 1 for examples. The spacing of the electrodes is within the electron's wavelength and therefore allows for quantum uncertainty / superposition effects to be in play. A biasing field is sometimes used to lift the energy level degeneracy via the Zeeman Effect, which defines the quantization axis (spin up or spin down). Quantum dots are so prominent in this field because they effectively behave as artificial atoms, which can absorb and reemit electrons, among other properties.[56,57]

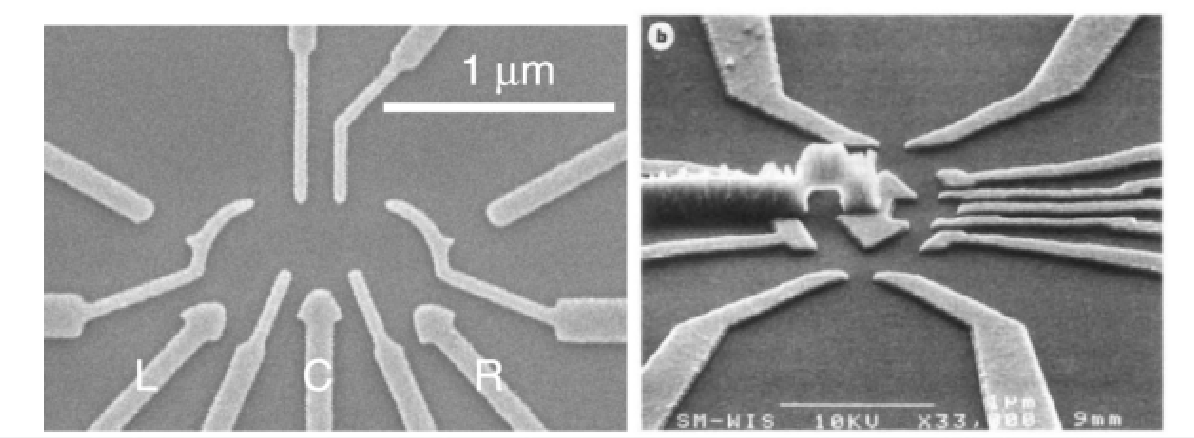


Figure 1. Scanning electron microscope images of two particular examples of quantum dots

Quantum Computation

Quantum computation involves the manipulation of qubits via one- and two-qubit quantum gates. The ability of qubits to be "entangled" quantum mechanically with each other and retain knowledge about the state of the system as a whole allows different types of computation than can be accomplished with conventional computing. Quantum computing will never replace conventional computation – most things that are done on computers today wouldn't benefit from being done on a quantum computer. However, certain problems are believed to have major advantages on a quantum computer. The major defense-related example is Shor's algorithm[58] (and to a lesser extent Grover's algorithm),[59] which allows for the relatively quick breaking of much current public-key cryptography. Currently, the question of which problems can be solved more efficiently on a quantum computer remains largely open; the general structure of quantum complexity classes and their relation to conventional complexity classes is not yet well understood, and there is at least one example of a "more efficient" quantum algorithm being redesigned to produce similar speed ups on conventional hardware.[60]

The fragile nature of qubits and delicate precision necessary to operate quantum gates means that quantum computation is subject to relatively large degrees of decoherence and error over even relatively small time scales, making error correction a necessary part of any scalable quantum computer. However, the nature of quantum mechanics (namely, the inability to simply clone or measure qubits without affecting them) means that error correction in quantum computers is much harder than the classical version of the problem, with current sentiment holding that hundreds or more physical qubits will be necessary to constitute a single, error-corrected "logical" qubit.

Quantum Cryptography, Key Distribution and Networks

Quantum Key Distribution, also known as quantum cryptography, involves using the central principles of quantum mechanics to securely generate keying material between two endpoints under the guarantee that the keying material has not been intercepted. It can be used to replace hand-couriered keying material. In some cases, it is possible to generate keying material sufficiently quickly to use it as a one-time pad, thus providing a total guarantee of secured communication.

There are three central protocols for quantum key distribution, two of which require the transmission of single photons (or, in practical situations, highly attenuated lasers) and the third of which does not require single photons but uses lasers and homodyne detectors. The first, commonly known as BB84,[61] depends on the fact that quantum measurements impact the state being measured; thus if an eavesdropper intercepts and measures the transmitted photons, they will have a measurable impact on the system. The second method (and its derivatives)[62] uses pairs of entangled photons transmitted to both users; in this case, interception and measurement will destroy the entanglement, again leaving a detectable impact on the system. A major advantage of the second method is the fact that entanglement can be "transferred"; this allows for the use of non-trusted quantum repeater nodes to improve the distance and speed over which a key can be generated. The third method is so-called continuous-variable QKD (or CV-QKD),[63] by using amplitude and phase modulation of a laser, QKD can be established with homodyne detectors rather than more expensive single photon detectors.

However, CV-QKD is generally, at this time, slower and less effective over distance than the BB84 protocol.

Quantum Metrology and Sensors

Quantum sensing is a very broad topic that is essentially defined as: the use of quantum phenomena to sense a particular quantity. Often times this is meant to imply that the motivation behind the effort is to achieve a better sensor (more sensitive, better resolution, etc.) than its classical counterpart. Classical sensors are limited by the shot noise limit. Which is the noise caused by the discrete nature of light (in optics) or charge (in electronics), or in general, the discreteness of quantum mechanics. Often times it is very difficult, if not impossible for classical sensors to approach the shot noise limit in sensitivity. Quantum sensors, operating on quantum scales and effects are more easily able to achieve this limit. In addition, quantum sensors can utilize the principle that the system can be conditioned such that the quantum noise becomes correlated. This allows quantum sensors (in some cases) to achieve better sensitivity than the shot noise limit, approaching the Heisenberg limit. The Heisenberg limit is the fundamental limit of nature in measurement error, and is due entirely to the physics of quantum mechanics, and not to the measurement device.[64]

An example of such a device is a squeezed light interferometer, such as what is used to measure gravitational waves.[65] This sensor correlates the quadrature fields (I and Q) of pairs of entangled photons in such a way that one particular set of quadratures becomes squeezed in variance, and the other set becomes anti-squeezed (broadened). This variance represents the noise in the quadrature measurement. The quadrature variance follows an uncertainty relation. The product of quadrature variance remains constant, but this squeezing effect allows one to have very low noise variance on one set, which is used to make measurements.

Quantum sensing is often times viewed as a much easier problem to solve than conventional quantum topics such as computing or communication. The reason for this is that the technologies used often times to not require as strict of requirements to perform well. For example, there is seldom need to ensure a large set of qubits or other very fragile propagating quantum state remain coherent. In addition, the problem at hand is usually much smaller in magnitude and scope. For example, sensing magnetic field strength is simple compared to performing Grover's algorithm for a practical problem with an N qubit quantum computer.

Information Operations Research Strategies: Getting Beyond Duck and Cover

Rebecca Anderson, Ph.D.

Abstract

Adversaries have had success with Information Operations (IO). Counter IO programs emphasize detection, characterization, disruption, and exposure of disinformation campaigns instigated by our nation-state adversaries and their proxies. These programs could be undermining efforts to develop tools capable of accessing the subtleties relating to cyber target disinformation reception by deliberately eliminating many of the important nuances of disinformation narratives before processing the data. Key recommendations to improve counter IO efforts include (1) using technology to access the meaning complexity that characterizes human languages and (2) disrupting adversarial influence operations in social media via rapid response

Background and Challenge

The Secretary of Defense characterizes Information Operations (IO) in Joint Publication 3-13 as “the integrated employment, during military operations, of information-related capabilities in concert with other lines of operation to influence, disrupt, corrupt, or usurp the decision making of adversaries and potential adversaries while protecting our own.”[66]

Adversaries seek information operations to:

- collect tactical information from US technological systems, and
- use propaganda, misinformation, and disinformation to influence people.

The fundamental challenge faced today is as follows. Adversaries have had success with information operations via information attacks facilitated by the vulnerabilities of many social media users, the adaptive-ness of social media, and an IO defense strategy that has not yet crystallized into an information advantage for the US.

Current strategies to countering information operations: Challenges and opportunities

Prior to our entry into World War II, U.S. leadership recognized that new technologies had introduced novel threats to the homeland, diminishing the protective potential afforded by our geographic boundaries. In response to this unprecedented danger, President Roosevelt established the Office of Civilian Defense for overseeing national and local civilian defense initiatives.[67] World War II civilian defense programs elicited Americans' "almost universal participation."[68] Civilian defense plans involved participants in concrete initiatives. Adults and children participated in air raid drills, black outs, and sand bag stockpiling; gathered scrap metal; collaborated in recycling drives; cultivated victory gardens; and, bought war stamps and bonds (*DHS* 7; Adatto 398).[69,70] Put simply, civilians contributed to the war effort, their contributions made an impact, and they were provided with meaningful evidence of that impact, from the food they cultivated in their victory gardens to letters of thanks they received from service members to awards and certifications for participation in war bond and other thrift campaigns.[71]

Threat-Response Mismatch

With the onset of the Cold War, the U.S. reached again for World War II strategies to defend the homeland. Cold War civilians, however, faced a set of circumstances different from those experienced by their World War II counterparts. Unlike the threats of World War II, nuclear weapons were characterized by complexity and shrouded in secrecy, preventing most Americans from grasping their intricacies. Cold War civilians built bomb shelters, stored provisions, and practiced *duck and cover* drills in the event of an attack for which their survival potential was arbitrarily dependent on the location of ground zero, not their preparedness. Intended to promote readiness, nuclear disaster preparedness measures may have undermined participants' self-efficacy by repeatedly exposing them to reminders that factors beyond their control were likely to render their training useless as their communities were vaporized. By the conclusion of the 1960s, many Americans sublimated their Cold War angst into expressions of cynicism, distrust, protests, and grim humor, such as the joke subverting the conventional question, "What are you going to be when you grow up?," that became popular with school children of the era: "What are you going to be *if* you grow up?"[72] Ultimately, Cold War civilian defense initiatives were not a good fit for the era's threats, and the mismatch had a detrimental effect on morale. Gradually, civilians withdrew from significant involvement in defense initiatives, leaving our military, scientists, diplomats, and politicians to manage the defense of our homeland.

Counter-IO initiatives against the current bifurcated threat to technology and information diverge from some aspects of the *duck and cover* approach, and resemble others. Unlike their Cold War predecessors whose participation in ineffective defense efforts undermined their sense of agency, cyber civilians exercise varying degrees of agency in defending their individual online navigation practices. Many civilians, for instance, opt to install antivirus software providing some protection from malware. They also practice defensive navigation that enhances user safety. Additionally, unlike their predecessors who experienced no nuclear attacks:

- cyber users navigate landscapes littered with malware, propaganda, and disinformation,
- increasing numbers of cyber users are falling victim to these attacks, and
- cyber users frequently do not recognize their victimization.

Reliance on experts recapitulates other aspects of the Cold War experience; for instance, like their Cold War, and like their Cold War predecessors, cyber experts guard against the more complex IO threats to technology and information. National and military leaders, policy makers, and government agencies work to minimize these attacks by monitoring and assessing IO, developing and implementing strategies and policy frameworks to counter IO attacks, partnering with industry, and alerting the public to threats that impact them. The cybersecurity industry contributes valuable layers of expert protections guarding the technological security of government agencies, large companies, and individuals. Security teams for IO-targeted platforms such as Facebook and Twitter use AI and human reviewers to detect IO-information in its various manifestations, from accounts to event pages to groups to
advertisements.[73,74] Despite important distinctions between Cold War and IO defense initiatives, in their reliance on experts, they have more in common with each other than differences.

Commonalities between the Cold War and cyber defense initiatives extend to their marginalization of civilians. Despite civilian capability parallels between World War II and the cyber era, cyber civilians are largely relegated to adopting a *duck and cover* stance as they navigate the treacherous online environment, focusing on self-protection instead of community protection. Rather than empowering the individual, cyber training experiences tend to orient them to their cyber constraints and limitations by emphasizing what they should ***not*** do in order to secure their safety. This, despite the fact that many Americans are conversant with technology, and the digital generation's early exposure to technology has facilitated cyber identities ranging from cyber-socialized to cyber-sophisticated for broad swathes of the population. The ubiquity of cyber expertise today reverses the scarcity of Cold War nuclear expertise, yet the considerable arsenal of civilian cyber capabilities is a community protection asset that remains largely unleveraged.

Current Gaps in Counter IO Defense

Counter IO programs emphasize detection, characterization, disruption, and exposure of disinformation campaigns instigated by our nation-state adversaries and their proxies. Specifically, these programs leverage advanced AI techniques, including Natural Language Processing (NLP), Machine Learning (ML), and visualizations, to automate detection of IO narratives, identify accounts engaged in dissemination of these narratives, and measure the scale of influence. Nation-state adversaries have access to the same advanced techniques used by our counter IO programs.

Currently, counter-IO programs undermine efforts to develop tools capable of accessing the subtleties relating to cyber target disinformation reception by deliberately eliminating many of the important nuances of disinformation narratives before processing the data. Incorporated in many counter-IO software packages, NLP routinely deletes punctuation, converts uppercase letters to lowercase, reduces words to their stems, and removes filler words.[75] Each of these removed or altered language features contributes meaning to disinformation narratives that is not only relevant but important.

Conclusions and Recommendations (need a version in the abstract)

Past successes of IO attacks have been facilitated by the vulnerabilities of many social media users, the adaptive-ness of social media, and an IO defense strategy that has not yet crystallized into a reconfiguration of the conflict to our advantage. Key recommendations to address these challenges are as follows:

1. Use technology to access the meaning complexity that characterizes human languages
    a. transform the escalating volume of decontextualized data from disorganized amorphousness into comprehensible and meaningful patterns enabling actionable insights
    b. Perform topological data analysis to investigate, understand, and contextualize communications emerging and evolving from layers of preceding communications, relating to contemporaneous communications.
        i. Topological data analysis is predicated on the ability to project the available data, especially text data, into some sort of space, exposing voids that could potentially be filled in a meaningful way.
2. Disrupt adversarial information operations in social media via rapid response.
    a. Rapidly respond to attacks in social media (persistently pivot) for disrupting the lethal adaptability of the Complex Adaptive System that is social media
3. Establish partnerships between civilians, industry, and all branches of government to develop and implement education initiatives from the ground level up for the purpose of coordinating a shift from adapting to IO attacks to resisting, disrupting, and rejecting them.

Ongoing work

ARL Penn State Counter-IO Programs: Selected Examples.

ARL Penn State has research programs focused on mitigating the challenges and contributing to the recommended courses of action. This includes the development of next-generation interdisciplinary capabilities that discover and develop insights about language and its evolutions, contextualized nuances, and networks of relationships. These program technologies can be leveraged for the development of interventions emphasizing proactivity over reactivity. Specific projects are detailed

1. **Automated Semantic Prosody.** Semantic Prosody (SP) is a subtle meaning nuance conveying information about cultural affiliation and group structure. Automated SP detection uses word n-grams (e.g., unigrams or bigrams) to detect words that frequently occur with positive or negative sentiment words, a detection capability beyond the scope of sentiment detection algorithms. For example, the unigram “commit” is often associated with negative contexts such as committing a crime, or committing suicide, while the bigram “commit to” is usually associated with positive contexts such as committing to a person, or committing to change. The detection of SPs enable insight into respondents’ attitudinal, evaluative, or emotional stance toward a given topic (Philip). Current SP technologies use a labor-intensive manual coding/tagging process that is not optimal. ARL Penn State has conducted preliminary experiments to develop a prototype SP detector using a mathematically-precise definition of SP (rather than an ad hoc definition), which has promise to transform SP detection from the current inefficient “human IS the loop” method to a more automated “human IN the loop method,” making it more practical for organizations with small analytic teams that cannot dedicate resources to tagging data.

    Researchers: C. Griffin, R. Anderson

2. **Automated Text Analysis and Visualizations for Light-weight Platforms.** Current clustering/analyzing/visualizing capabilities offer intelligence analysts unwieldy and inefficient tools for evaluating high-volume/poor-quality data streams. BANSHEE resolves these shortcomings, providing analysts the means to quickly group and visualize large volumes of data, to tailor further collection, and to score and interpret new information. The core algorithms perform across multiple languages, including English, most Western European variants, Russian, Chinese, Arabic, and Farsi. Its interface ensures ease of use. Versatile design enables the technology to function either as a modular component in existing environments or as a stand-alone.

   Researchers:

   Current Team: C. Taschner, D. Del Vecchio, C. Griffin, R. Fraleigh, D. Jones, R. Anderson, and K. Kuczynski (2020 - present)

   Legacy Team: B. Bickel, D. Del Vecchio, C. Griffin, C. Taschner, and R. Fraleigh, (2017 – 2020)

3. **Modeling IO Behaviors using Dynamical Systems.** Dynamical systems are functions describing changes over time. Conventional two-dimensional time maps present static pictures that may erase or distort contextual information. Dynamical systems diagrams leverage human cognitive preferences for information packaged as narrative characterized by temporal organization, coherence, causality, and sensory information, to show system evolutions, describing future states following from the current state. Using dynamical systems to model Russian IO Twitter data, ARL Penn State researchers developed a mathematical model to describe the per-day tweet production, extracted from a large set of data using spectral analysis, asserted to represent a Russian influence operation and released by Twitter Inc. Researchers showed that this mathematical model allowed them to construct families (clusters) of users with common dynamics. They defined a labeling scheme describing user strategy in an information operation and showed that the resulting strategies correspond to the behavioral clusters identified from their harmonics. Ongoing work in this area is attempting to determine whether the dynamics of user tweets can be described by partially predictable chaotic systems (e.g., like the Lorenz system). If so, it is possible that specific chaotic dynamics may allow researchers to separate legitimate user behavior from influence operations even when they share common harmonics.

   Researchers: S. Rajtmajer, A. Simhachalam, T. Zhao, B. Bickel, and C. Griffin. A Dynamical Systems Perspective Reveals Coordination in Russian Twitter Operations. ArXiv, 2020.

4. **Modeling Emergence of IO Communities, Their Operational Characteristics, and Transnational Scope.** ARL Penn State researchers developed and used a collection of statistical methods (unsupervised machine learning) to extract relevant information from a Twitter supplied data set consisting of alleged Russian trolls who allegedly attempted to influence the 2016 US Presidential election. These unsupervised statistical methods allow fast identification of (1) emergent language communities within the troll population, (2) the transnational scope of the operation and (3) operational characteristics of trolls that can be used for future identification. Using natural language processing, manifold learning and Fourier analysis, researchers identified an operation that includes not only the 2016 US election, but also the French national and both local and national German elections. The ARL Penn State team demonstrates the resulting troll population is composed of users with common, but clearly customized, behavioral characteristics.

Researchers: C. Griffin and B. Bickel. Unsupervised Machine Learning of Open Source Russian Twitter Data Reveals Global Scope and Operational Characteristics. ArXiv Paper, 2018.

5. **Social Engineering Defense Tool.** Adversaries are actively using social engineering to elicit Controlled Unclassified Information research, Intellectual Property, and Department of Defense (DoD) related research. ARL Penn State is developing technology to identify, mitigate, and lower risks of foreign influence by helping researchers critically evaluate a landscape of unsolicited messages or any corpus of textual data within the context of organization's research profile (research expenditures and public research profile) and key research contributors.

   Program technology leverages a suite of machine learning tools (TRL8) and interactive visual analytics to help researchers critically evaluate the most relevant messages and linguistic patterns related to key intelligence questions. Prototyped on a corpus of unsolicited, self- volunteered emails to the ARL Penn State security team, messages were parsed for conversational ask (e.g. requests to join a talent program including Thousand Talents program and its affiliates) and categorized using unsupervised linguistic topic analysis. This information was correlated against the ARL Penn State organization chart, employee roles, and the organizational public research persona and presented in a browser-based visual analytic web application for rapid interactive querying, exploration, and critical evaluation.

   This ARL Penn State program serves as a template for academic and government organizations to derive context for current and emergent undue foreign influence operations. More broadly, this program assists in the early detection of potential threats, transparent education of researchers and staff to emerging social engineering techniques, and provides analytics to support swift actionable responses to potential threats from our adversaries.

   Researchers: M. Hohnka, K. Kuczynski, and R. Fraleigh

Internal Science and Technology Program

Overview

The purpose of the Internal Science and Technology Program (ISTP) is to maintain the Applied Research Lab (ARL) as a center of excellence by fostering and capitalizing on promising "good ideas" that align with the ARL mission, expand ARL science and technology (S&T) capabilities, strengthen ARL core competencies, enable strategic opportunities, and address sponsors' present and future needs. ISTPs produce S&T advances that reduce technical risk, increase cost effectiveness, enhance staff expertise, and embody transformative solutions to challenging problems of direct relevance to sponsors and the nation. While ISTP projects may relate to any topic, certain topics are high-priority areas of interest currently, such as: data science for influence operations and gray zone operations, especially with regard to using social media and other open source data; data architectures, infrastructure, tools, and network technologies that support the Navy's Project Overmatch concept (in which sensors and shooters are linked across domains); cyber electromagnetic maneuver warfare (including C5ISRT and Counter-C5ISRT); undersea environmental sensing and operational exploitation; technical approaches to trusted Machine Learning and autonomy; communication and navigation technologies that support / enable deep ocean capability; unsupervised ML approaches; and, analytics and applications (in general) that transform data into actionable information. CINOs current internally funded projects are:

1. Marine Outboard Cyber Electromagnetic Maneuver Warfare (C-EMW)
2. Tactical Multi-Domain Optical Communications Relay
3. Geophysical Data Fusion for Deep Water Navigation
4. Detecting Adversarial Attacks Against Machine Learning (ML) Systems
5. The Development of Task-dependent metrics for Full Motion Video (FMV) Saliency
6. Application of Machine Learning (ML) Algorithms to Global Positioning System (GPS) Spoofing Detection
7. Frequency Diverse Antenna Array for Cognitive Communications and Radar Applications
8. Enhanced Social Media Filtering in the Information Operation Space

Marine Outboard C-EMW

Principal Investigator (PI): Dr. Erik Lenzing

Background

This project is for the research and development of a marine-vessel.

This falls in the area of cyber electromagnetic maneuver warfare (C-EMW).

Goals and Tasks

This research will provide specific data on optimal frequencies.

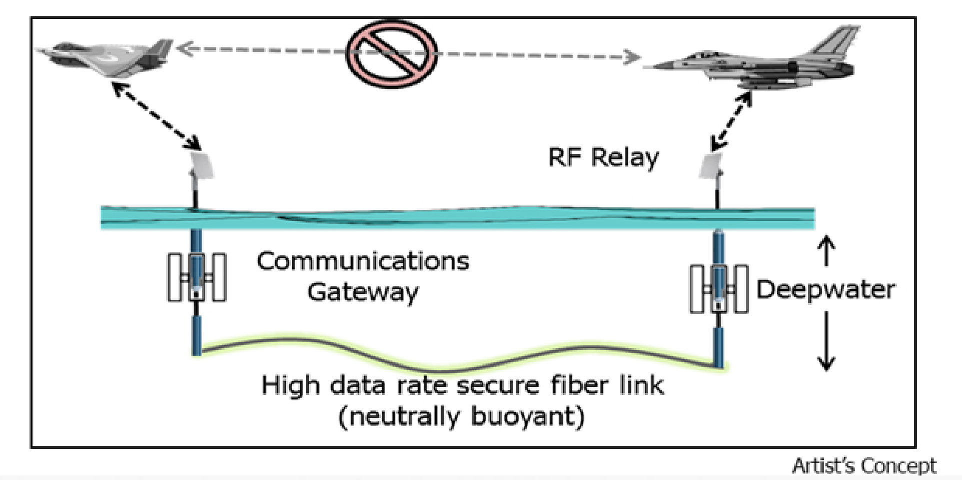
Potential Impacts

The results of this research will give Navy sponsors highly valued information for decision making and planning against this very serious threat.

Tactical Multi-Domain Optical Communications Relay

PI: Aaron Bell

Figure 2.1 Air Water Interface



SOURCE: DARPA

Background

Communications between undersea systems and above surface systems (e.g., surface vessels, aircraft, satellites, etc.) require either the undersea system breaching the surface or deploying an air-water interface, typically a buoy, to establish an acoustic to RF communications link. The Defense Advanced Research Projects Agency-Tactical Undersea Network Architectures (DARPA-TUNA) project[76] is an example, as illustrated in Figure 2.1, above.

Issues involved with undersea acoustic communications are well documented. The objectives of this project are to:

- execute a technology assessment of multi-domain (i.e., sea, land, air, space) tactical free-space optical communications (OCOMMs) solutions,
- identify technical areas of opportunity (e.g., Air-Water Interface) to strategically develop OCOMMs solutions, and
- fuse existing yet disparate capabilities at ARL to establish a baseline point-of-entry to provide OCOMMs solutions in support of the U.S. Navy's Project *Overmatch* and DoD's Joint All-Domain Command and Control (JADC2) vision.

Goals and Tasks

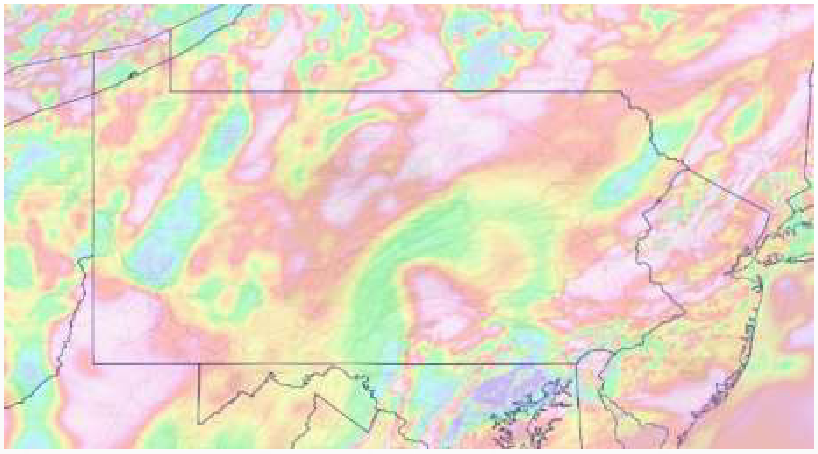
The goal of this project is to strategically position PSU-ARL to provide relevant technical solutions in the emerging OCOMMs technology realm for U.S. Navy and other Department of Defense (DoD) or government end users, as well as augment the lab's existing capabilities in optical sensors, multi-domain communications, and sea-based systems engineering. It also has the benefit of tackling the growing risk of conflict with near-peer competitors head-on, therefore increasing the need for reliable, diverse, distributed, alternative means of multi-domain communications to connect the "best shooter with the best sensor" for data exfil and infil. OCOMMs is an under-developed technology in this area and this project seeks to address that.

Potential Impacts

There is potential for optical communications to provide an alternative means of communication between undersea systems in particular mission scenarios, avoiding the above-mentioned issues related to acoustic and fiber optic communications. This project will investigate the viability of undersea optical communications while identifying its associated technical challenges and gaps. Similar to undersea acoustic communications, RF communications can be non-ideal when operating in a clandestine manner due to its susceptibility to detection (visual, radar, and emissions), interception, and jamming. There is potential for optical communications to provide an alternative means of communication involving both undersea and above sea systems. An optical communications system could provide the potential for a tactical low probability of detection/low probability of intercept (LPD/LPI), jam-resistant communications link.

Geophysical Data Fusion for Deep Water Navigation, PI: Armond Conte

Figure 3.1 Magnetic Anomaly Map of Pennsylvania



SOURCE: United States Geological Survey[77,78]

Background

In deep-sea navigation, the use of a Global Positioning System (GPS) is not an option, therefore other methods of determining own-ship position are required. Current deep-sea navigation systems in development at ARL use alternative geophysical data types to estimate position.

Goals and Tasks

The objective of this project is to explore data fusion approaches for deep-sea map-matching navigation algorithms that use bathymetry, gravitational fields, and magnetic fields. Measuring bathymetry requires the use of an active sonar that emits sound to obtain depth estimates. Conversely the gravitational and magnetic fields respectively require a gravimeter and a magnetometer, and passively sense their environments without the need to transmit energy into the environment. For each of these geophysical data types, a map-matching algorithm is being developed. The map-matching algorithm compares measurements to pre-existing maps in order to determine the location of the sensor that collected the measurement, with a goal of obtaining increased confidence in position over time. Despite the advancement of map-matching technology at ARL, there does not yet exist a means to combine the output of each of these navigation algorithms.

Potential Impacts

The benefits are a mix of technical and competency.

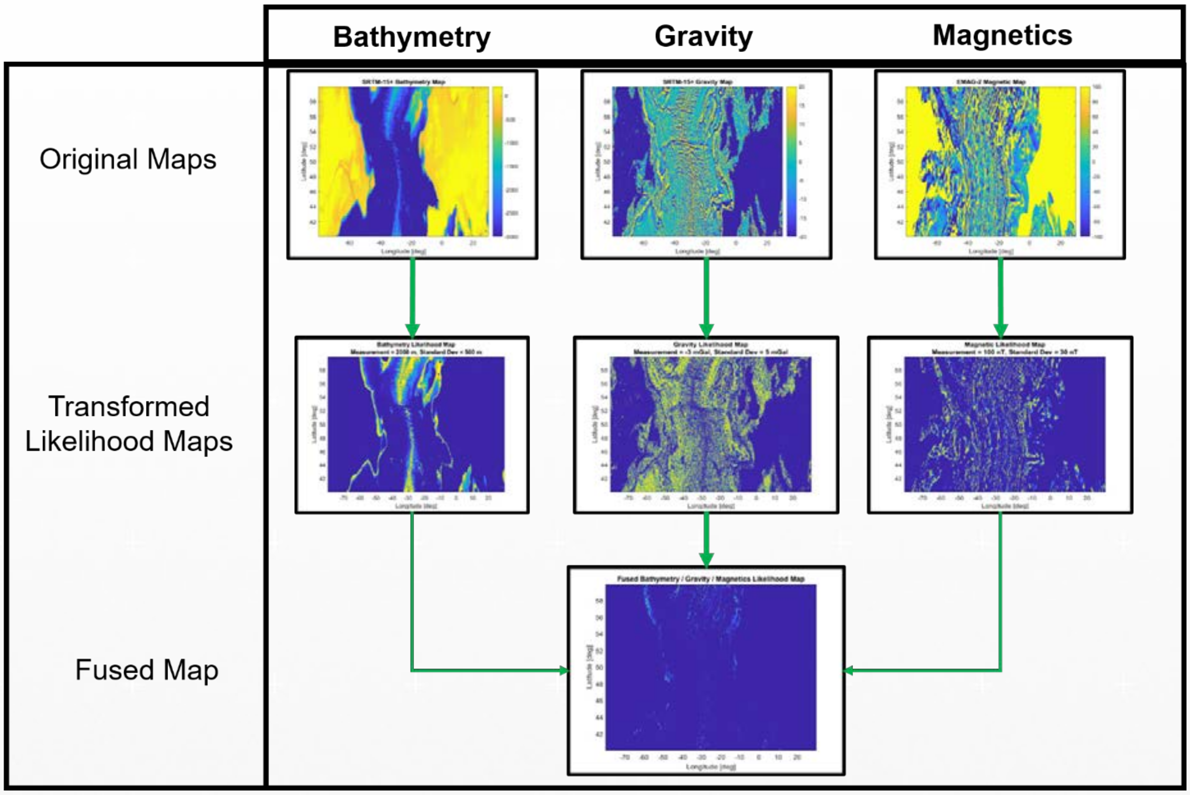
- **Technical** – Fusing the estimates derived from each geophysical map-matching algorithm will result in more accurate and simpler estimates of the navigation solution that can be provided to the end user. The benefit of simplicity leads directly to an increase in efficiency.
- **Competency** – ARL has three funded programs to develop individual map-matching estimation algorithms. The development of a fusion algorithm would need to either be funded separately or in a combined manner. The development of these techniques through this ISTP will give ARL a head-start in building a fully combined geophysical state estimation algorithm that is of interest to the primary sponsor.

The major innovation introduced in this project is the fusion of estimates coming from each of the individual sensors. Considering the active nature of sonar in this problem, in conjunction with the passive gravimeter and magnetometer, the fusion of these estimates would advance towards a full geophysical solution to the deep-sea navigation problem. It is expected that there will be some overlap in information that can be derived from each of the individual sensor types and, as a part of this work, that the level of correlation between the different data types will be characterized. If successful, this work will show that there are benefits to fusing the data from more than one source, rather than treating the geophysical maps as three separate entities and three separate sources. Algorithms resulting from this work will refine the navigation solution, providing better information to the user.

Accomplishments

During this project a method of transforming geophysical maps from each modality into a "likelihood map" was developed. The likelihood map estimates the probability that a measurement from the sensor of a given geophysical modality was taken at each pixel location on the map, while simultaneously providing both a visual and analytical resource. This transformation also places the information contained in each of the maps into a space where they can be mathematically combined, under the assumption that each measurement comes from an independent sensor. The result is a new likelihood map with a more constrained region. Additional studies were successfully performed that portrayed the effect of diminishing returns resulting from consecutive similar measurements, as well as the potential for adding non-geophysical sources of navigation information. The work done in this ISTP opens the door to enhancing a geophysical navigation solution using multiple sources in a new illustrative manner.

Figure 3.2 Converting Maps into Likelihood Maps Followed by Fusion



Sources: Original Bathymetry[79] / Gravity[80] Maps (UCSD, SCRIPPS), Magnetic (NOAA)[81]

Detecting Adversarial Attacks against Machine Learning Systems

PI: Brandon Daubenspeck

Figure 4.1 Integrating Machine Learning

SOURCE: Creative Commons[82]

Background

This project will apply improvements to the Deep k-Nearest-Neighbors (DkNN) algorithm to increase the accuracy of a Deep Neural Network (DNN) and enable improved automated assessment of the likelihood that input to a DNN has been maliciously modified by an adversary. This project will build upon prior ARL research to develop a technical approach for assuring the correct operation of neural networks in the presence of adversarial inputs. The improved algorithm will also provide a mechanism to support analysis of the function of each inner layer of a DNN, potentially yielding greater insight into the ways that these traditionally “black box” systems make their classification decisions. In addition, this project will deliver a report detailing how the improved DkNN algorithm works and how much improvement in accuracy and assurance it achieves over the baseline DkNN algorithm and other current best practices. It will also deliver a software implementation of the improved algorithm that can be referenced for incorporation into other ARL projects and used to support analysis of the inner layers of supported DNNs.

Goals and Tasks

The objectives are to develop a technical approach to assure correct operation of neural networks in the presence of adversarial inputs, upgrade the DkNN algorithm to improve its accuracy and the level of assurance that it can provide, and create a report and software to enable technology to be applied to any DNN being developed at ARL.

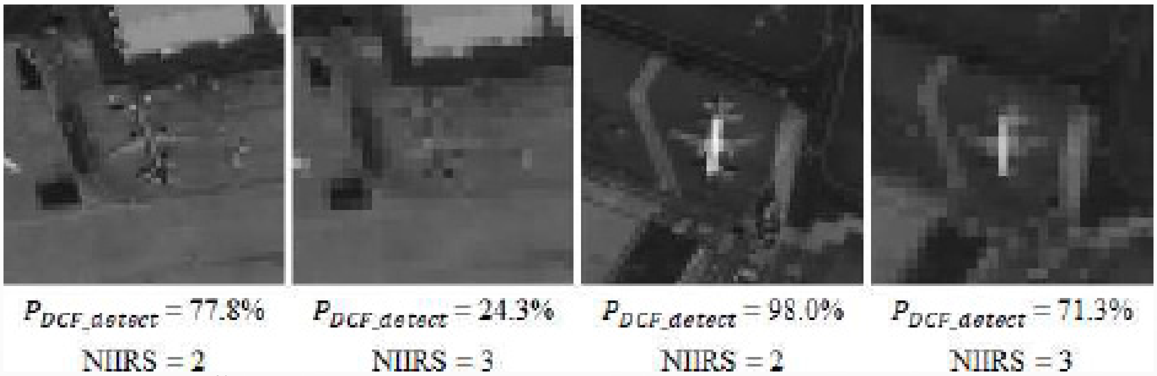
Potential Impacts

The benefits will be numerous. This project will provide a combination of scientific, technical, and competency benefits. Scientific benefits will include increased insight into the inner workings of DNN-based machine learning/deep learning (ML/DL) systems, which currently function largely as “black boxes.” The particular insights that might be gained include knowledge about the function of various internal layers in different DNN architectures and knowledge regarding the performance of the various proposed DkNN optimizations for different classes of input data. These benefits will be captured in a report at the conclusion of the project. Technical benefits resulting from this project will include a software implementation of an upgraded DkNN algorithm that can be used to upgrade any DNN-based ML/DL system to increase its resilience against adversarial attacks. The software implementation of the algorithm will also make it possible to more easily evaluate the functions of the inner layers of any DNN with which it is used. Competency benefits resulting from this project will include having ARL personnel develop a novel trust assurance mechanism for DNN-based ML/DL systems that will potentially yield higher accuracy and trust assurance levels than any alternative mechanisms currently available. This project has the potential to make ARL a national leader in technical approaches for trusted ML.

The Development of Task-dependent Metrics for Full Motion Video Saliency

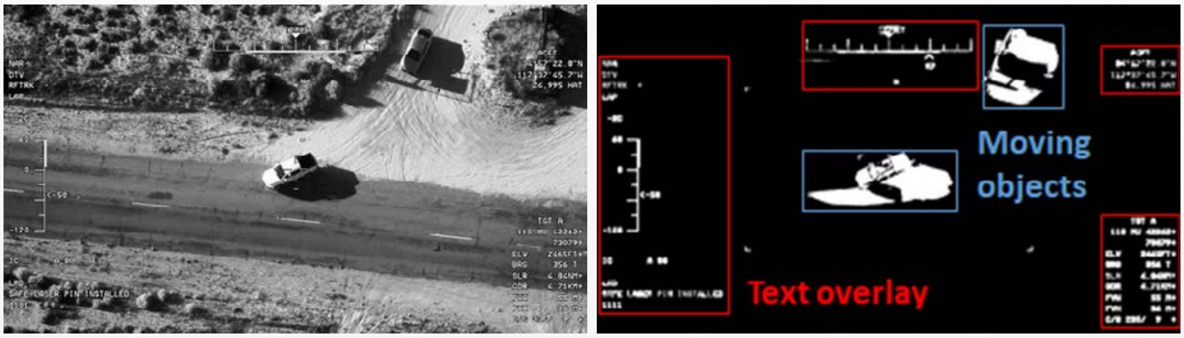
PI: John Morgan

Figure 5.1 Worldview 3 Images[83]



SOURCE: The RarePlanes Dataset[84]

Figure 5.2 Motion Segmentation[85]



Background

At a high level there are three functions that must be performed on FMV: tasking, searching, and reviewing. Tasking is the determination of what FMV to collect, but currently FMV products are not being tasked efficiently because popular products are overtasked and FMV is being collected that may not be suitable for the given application. Searching is the process of identifying which videos and video segments will help answer an intelligence question, but currently there is more video data available than can be viewed by analysts.

Reviewing is the actual analysis of a video, which is time consuming and can be facilitated by tools for automating specific tasks. This project will coordinate with government partners to direct research and development into solutions for each of these areas of interest.

Goals and Tasks

FMV is a novel domain for PSU-ARL, and the goal of this project is to build the necessary expertise to develop whitepapers and demonstrations in order to secure future funding. We will also reach out to our government partners that utilize FMV to gain an understanding of their needs, which will direct additional research in order to build up a set of technologically relevant skills that can be applied throughout the intelligence community with direct contacts to sell them. Initially we will focus on video quality metrics, video summarization, and machine learning for instance segmentation. Video quality metrics measure how applicable a video is for a given application, which is useful for tasking to determine how suitable a collect will be ahead of time, and is useful for searching to rank existing videos based on quality. Video summarization is the process of creating a concise summary from just the important components of a video, which is useful for searching because the summaries can be browsed more efficiently. Instance segmentation is the process of detecting individual instances of specific types of objects in a video, which is useful for reviewing because it eliminates the need to manually find objects in the video. For each of these topics we will conduct a literature review and create demonstrations where possible.

Potential Impacts

FMV is an important tool in persistent intelligence, surveillance, and reconnaissance (ISR) systems. PSU-ARL is in need of additional FMV-related capabilities as this technology becomes more accessible to the communities we support. By reaching out to our partners and developing contacts we can provide internal documentation of government needs as well as our research, thus making PSU-ARL more prepared to compete in this domain.

Accomplishments

White papers funded:

- Exploring image transformers for feature matching: $1,000,000 / 12 months

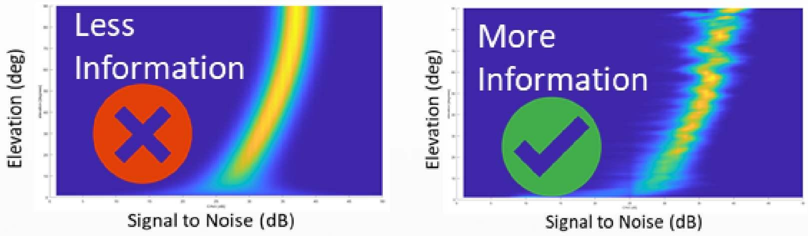
White papers in progress:

- Quantitative approach for assessing the representativeness of FMV ML model training datasets
- Text extraction
    - Text overlay extraction
    - Text recognition in the wild
- What metadata is needed to determine if an FMV product is applicable to a problem
- Improved video quality metrics for smarter tasking of products
- Quantitative approach to assessing the relevance of a FMV ML model to a new dataset
- Research & Development of a metadata standard to facilitate matching an FMV ML capability to an application
- Test and Evaluation, mission-relevant metrics development for FMV capabilities

Application of Machine Learning Algorithms (ML) to Global Positioning System Spoofing Detection

PI: David Redington

Figure 6.1 Modeled (left) and Empirical (right) Probability Mass Surfaces Relating Satellite Elevation Angle to Signal to Noise Levels



SOURCE: Penn State Applied Research Laboratory

Background

GPS is a complex system and it is virtually impossible for a spoofing system to mimic all of its nuances. The idea for this internal research project is to leverage modern Artificial Intelligence (AI) Machine Learning (ML) techniques to understand how the multitude of nuances in GPS can be used to detect when a spoofing attack is occurring. The impact of this study is directly applicable to programs that utilize GPS. Autonomous unmanned systems get the greatest benefit, as there is no person in the loop to indicate if the GPS solution is reasonable. ARL's Navigation Research and Development Division (NRDD) works with several sponsors that utilize GPS equipment on surface and subsurface systems, including Program Executive Office Integrated Warfare Systems 6 (PEO IWS 6) and Strategic Systems Programs (SSP). In Unmanned Underwater Vehicles (UUV) and other Underwater Vehicles (UV) obtaining a GPS position fix is required periodically to update inertial navigation systems. A UUV must surface to obtain a GPS fix and minimizing the surface time is critical to maintain covert operations. In these conditions, the validity of GPS fix data must be assessed rapidly and with high confidence. The detection technique proposed here targets both the validation speed and validation confidence, which are required by UUV's navigation systems.

Goals and Tasks

Detection of spoofing attacks is the fundamental objective in this study. This project seeks to establish an effective method to increase the security of GPS dependent systems and infrastructure. GPS dependent systems have two main vulnerabilities — jamming and spoofing. A jamming attack simply denies a GPS receiver access to GPS signals. In a jamming attack, the GPS receiver is aware of the attack because of the disrupted access to GPS signals. Spoofing attacks are more sophisticated and covert. In this type of attack, the GPS receiver is sent counterfeit signals which appear to be genuine GPS signals.

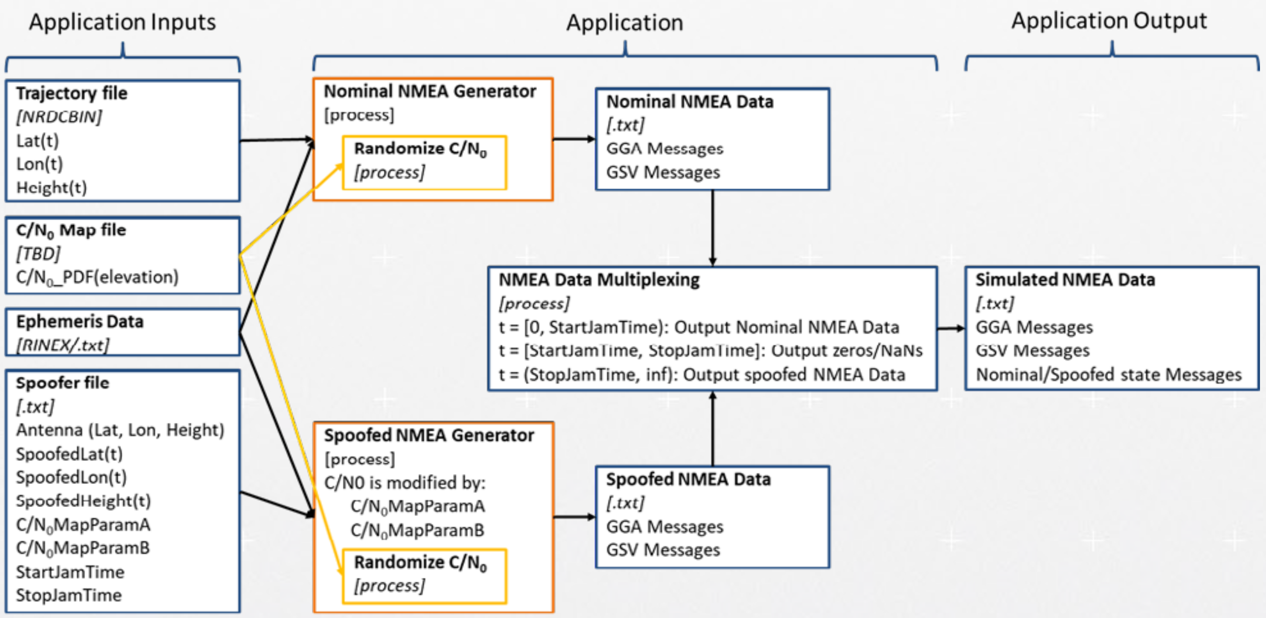
Potential Impacts

This study's benefit is both technological and competency. Tackling the GPS spoofing detection problem using the techniques developed will provide a better and more robust option to pre-existing solutions. This would benefit the navigation community including PEO IWS 6 and SSP. By investigating the problem of spoofing detection, NRDD will be in a position to leverage AI/ML in the other navigation domains. At a high-level, the type of spoofing detection process that is being discussed is very flexible. In other words, this detection process could be implemented in broad range of platforms. The resulting detection algorithm would not require any platform hardware changes, and could be executed in parallel with other platform system processes. At a laboratory level, the result of this study will produce an AI/ML implementation, applied to a positioning, navigation, and timing (PNT) problem that will help retain ARL's reputation as capable of solving current problems with modern engineering techniques. This project will also help retain ARL's reputation as capable of solving current problems with modern engineering techniques.

Accomplishments

The need for large amounts of training and test data was the driving motivation for the projects current accomplishments. For practical purposes, software was developed to generate simulated GPS receiver messaging data. Coded data is required in ML training algorithms. To facilitate the ML development, the simulation software was developed to generate coded data that contained artifacts of benign and spoofed GPS environments. A software design diagram of the simulation software can be seen in Figure 6.2.

Figure 6.2 GPS Receiver Data Simulator Software Design Software

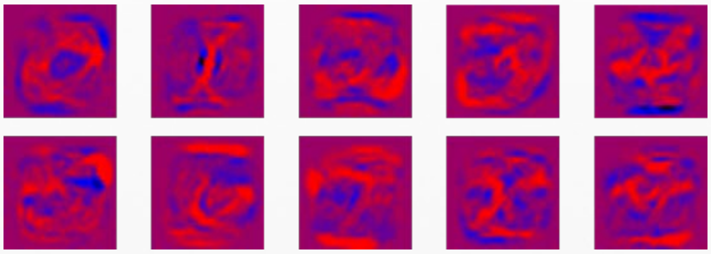


SOURCE: Penn State Applied Research Laboratory

This simulation software was designed to inject well understood spoofing artifacts into the output data by manipulating Carrier-to-Noise ratios (C/N0) of the each received satellite vehicle (SV) signal. This allows the ML training process development to focus on a well understood spoofing artifact. Since the simulation software produced more than just C/N0 data, ML training sensitivity is not limited to only C/N0 artifacts. The data generation process is also designed to include environmental randomization to provide realistic scenarios and variation needed for successful ML training operations. To date this software is approximation 80% complete. It is capable of accepting most of the needed application inputs and can generate data with adequate accuracy of a benign GPS environment.

While much of the project's focus has been in data generation thus far, the ML training processes have been researched and exercised. As an example, Figure 6.3 shows some ML training algorithm results.

Figure 6.3 ML training exercise using MNIST database of handwritten digits



Frequency Diverse Antenna Array for Cognitive Communications and Radar Applications

PI: Tyler Ridder

Figure 7.1 Satellite Array

SOURCE: Creative Commons[86]

Background

An angle and range-dependent radiation pattern has many different applications by U.S. Government (USG) customers and Research, Development, Test and Evaluation (RDT&E) sponsors, including radar technology, communications systems, electromagnetic security, and directed technologies. Communications systems will benefit from a frequency diverse array (FDA) in many different ways. The first advantage of an angle and range-dependent radiation pattern is the use of directed energy. By creating an angle and range-dependent radiation pattern, the communications system will be able to send energy to a specific location in space. This has major advantages in multiple-input-multiple-output (MIMO) systems that utilize a communication link with multiple nodes in a distributed geometry. An angle and range-dependent radiation pattern has the potential to significantly reduce a system's probability of intercept, or the probability of being detected by an adversary.

Goals and Tasks

This project seeks to investigate the use of FDAs for various applications in communications and radar systems. These applications include, but are not limited to, electromagnetic security; radar target detection and tracking; and, jamming and anti-jamming scenarios. The project consists of a multi-year approach in which the first year would characterize and investigate FDA applications through simulations and outline a path forward for hardware. The second year would implement the hardware design for experimental measurements and comparisons to our modeled results. Objectives for the first year of this project are to:

- further develop theoretical understanding of FDAs.
- develop optimal FDA designs for various use-case scenarios including communications systems, radar target tracking, and jamming scenarios.
- compare these results with current phased array technology to show the advantage of FDAs.
- design a procedure to build and test FDAs for phase 2 of this project.

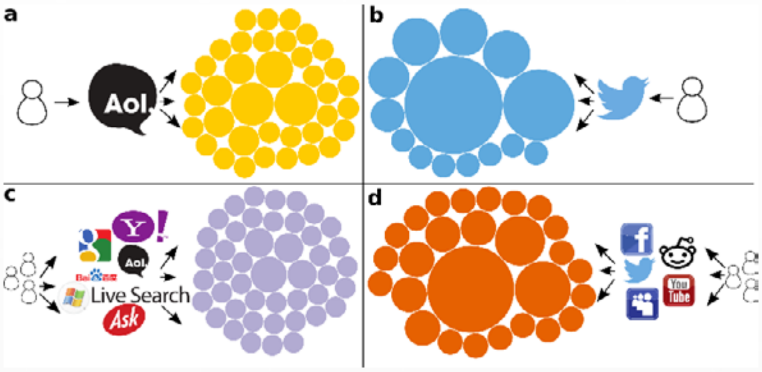
Potential Impacts

Previous ARL projects have focused on the transmission capabilities of the FDA, however, the receiving capabilities follow the same logic. The FDA can be used to receive signals from a specific location while blocking our energy from other areas. This is a major advantage in the presence of jammers. An FDA will be able to block out energy that is emanating from the location of the jammer while allowing the energy to be received from the rest of the environment. By the end of this project, we will have the scientific ability to design, simulate and construct a real-world FDA. With the capabilities possessed by the Antennas and Electromagnetics Department, we will be able to design, model, and simulate a physical realizable FDA. The knowledge learned in the process of the project work will directly translate to future sponsor needs of the rapid development and prototyping of unique antennas and antenna arrays. The FDA development is a next generation antenna design that will keep ARL ahead of the curve of electromagnetic superiority.

Enhanced Social Media Filtering in the Information Operation Space

PI: Ken Smith

Figure 8.1 Social Media Filtering



SOURCE: Creative Commons[87]

Background

In their paper, "Social Media Usage Patterns during Natural Hazards,"[88] Niles, M.T. et al., discuss increases in social media usage and how that can be tied to disaster relief. Given the popularity of social media and the ability to push information to the masses quite easily, this is to be expected. With the increase in social media traffic, this corpus of data is a largely untapped source of potentially significant, real time informational data. Many agencies and policy makers have realized the value of information from such sources and how it could be used to assist them in planning for and reacting to a crisis situation, such as during recent Hurricane Sandy.

Goals and Tasks

This project proposes to create an easy, expandable, user friendly, software framework to cultivate and extract "wanted" or "tailored" information from such social media sources. Extracted data could then be analyzed in real time and presented to an operator in a set of displays and used for decision making. The end goal of this project is to ultimately create a decision aid that can be used by Emergency Management Personnel to assist with disaster recovery planning and management. To do so, this project will design and develop an emergency management decision aid to address the shortcomings outlined above. Specifically, a software framework will be developed that is problem agnostic and versatile that can be used to ingest social media feeds, perform intelligent analysis, and then display the results in an intuitive manner to the disaster relief personnel. Traditionally, most social media tools focus on twitter feeds. This project will expand the data corpus by including Instagram, and, if the event is significant, pull and analyze news media data feeds.

Potential Impacts

The benefits of this project will be the advancement of ARL's understanding of and capabilities within the Social Media Information Operations space via the development of techniques to pull and aggregate social media feeds other than twitter. It will also demonstrate a software framework that can be used in current/future social media projects. ARL will also have a deeper understanding of ingesting, data aggregation, and data analysis of social media data sources, as well as advance the ARL's capability and lay groundwork for future projects requiring social media data. This project would provide a novel tool to improve overall situational awareness. Once completed, the decision aid can be used to demonstrate, in an unclassified environment, what can be extracted from social media data aggregation and used within the Influence/Information Operations space.

One final note on this project is that a potential sponsor has been identified. Previous discussions with the Coast Guard have their interest in work along these lines. Their specific application would be a tool that could help in disasters such as the major hurricanes that have occurred over the past several years. Their belief is that by aggregating social media data they will get a better, real time picture of what is happening across the entire impacted area thus allowing them to make better response decisions and asset allocation. Other potential users would include the Federal Emergency Management Agency (FEMA), the Pennsylvania Emergency Management Agency (PEMA), the American Red Cross, and city or state governments.

Accomplishments

Thus far, the project has developed a software visualization analysis tool using real-time ingested social media data sources for the aid in decision making in Emergency Management and Operational Information spaces.

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Chen, Y., Belmonte, A., & **Griffin, C.** (2021). Imitation of success leads to cost of living mediated fairness in the Ultimatum Game. *Physica A: Statistical Mechanics and its Applications, 583,* [126328]. https://doi.org/10.1016/j.physa.2021.126328

In this paper, we analyze a social imitation model that incorporates internal energy caches (e.g., food/money savings), cost of living, death, and reproduction into the Ultimatum Game. We show that when imitation (and death) occurs, a natural correlation between selfishness and cost of living emerges. However, in all societies that do not collapse, non-Nash sharing strategies emerge as the de facto result of imitation. We explain these results by constructing a mean-field approximation of the internal energy cache informed by time-varying distributions extracted from experimental data.

Gerg, I. and Monga, V., "Real-Time, Deep Synthetic Aperture Sonar (SAS) Autofocus," 2021 IEEE International Geoscience and Remote Sensing Symposium IGARSS, 2021, pp. 8684-8687, doi: 10.1109/IGARSS47720.2021.9554141

Synthetic aperture sonar (SAS) requires precise time-of-flight measurements of the transmitted/received waveform to produce well-focused imagery. It is not uncommon for errors in these measurements to be present resulting in image defocusing. To overcome this, an \emph{autofocus} algorithm is employed as a post-processing step after image reconstruction to improve image focus. Our results demonstrate Deep Autofocus can produce imagery perceptually better than common iterative techniques but at a lower computational cost. We conclude that Deep Autofocus can provide a more favorable cost-quality trade-off than alternatives with significant potential of future research.

Lennon, P., **Fraleigh, R.**, van Scoy, L., Keshaviah, A., Hu, X., Snyder, B., Miller, L., Calo, W., Zgierska, A., and **Griffin, C.**, (2021). "Developing and testing an automated qualitative assistant (AQUA) to support qualitative analysis," Family Medicine and Community Health, 9(Suppl 1), e001287. https://doi.org/10.1136/fmch-2021-001287

Qualitative research remains underused, in part due to the time and cost of annotating qualitative data (coding). Artificial intelligence (AI) has been suggested as a means to reduce those burdens, and has been used in exploratory studies to reduce the burden of coding. However, methods to date use AI analytical techniques that lack transparency, potentially limiting acceptance of results. The aim of this manuscript is to describe pertinent components of best practices of AI/machine learning (ML)-assisted qualitative methods, illustrating how primary care researchers may use AQUA to rapidly and accurately code large text datasets. The contribution of this article is providing guidance that should increase AI/ML transparency and reproducibility.

Nakshatri, N., Menon, A., Giles, C., Rajtmajer, S., and **Griffin, C.**, (2021). “Design and analysis of a synthetic prediction market using dynamic convex sets,” Results in Control and Optimization, 5, 100052. https://doi.org/10.1016/j.rico.2021.100052

We present a synthetic prediction market whose agent purchase logic is defined using a sigmoid transformation of a convex semi-algebraic set defined in feature space. Asset prices are determined by a logarithmic scoring market rule. Time varying asset prices affect the structure of the semi-algebraic sets leading to time-varying agent purchase rules. We show that under certain assumptions on the underlying geometry, the resulting synthetic prediction market can be used to arbitrarily closely approximate a binary function defined on a set of input data. We also provide sufficient conditions for market convergence and show that under certain instances markets can exhibit limit cycles in asset spot price. We provide an evolutionary algorithm for training agent parameters to allow a market to model the distribution of a given data set and illustrate the market approximation using three open source data sets. Results are compared to standard machine learning methods.

Umar, P., Squicciarini, A., **Griffin, C.**, and Wede, J., “Contagion of offensive behavior for transient interactions in online commenting platforms,” International Journal of Human-Computer Interaction, October 4, 2021.

Online aggression is an increasingly significant problem in Internet-based communication systems (e.g., commenting platforms) with potentially negative effects on online participation and quality of online discourse. Similar to offline aggression, online aggression has been shown to be contagious and to spread through online platforms as a result of exposure to aggressive content. The results in this paper support the hypothesis that even in transient online interactions, young adult participants mimic their peers in an attempt to minimize social stress. Moreover, this mimicking occurs even when the participants know they are participating in an artificial social system.

Wu, S. Jiang, L., He, X., Jin, Y., **Griffin, C.**, and Wu, R., (2021). “A quantitative decision theory of animal conflict,” Heliyon, 7(7), e07621. https://doi.org/10.1016/j.heliyon.2021.e07621

Interactions between individuals are thought to shape evolution and speciation through natural selection, but little is known about how an individual (or player) strategically interacts with others to maximize its payoff. We develop a simple decision-theoretic model that generates four hypotheses about the choice of an optimal behavioral strategy by a player in response to the strategies of other players. Given the ubiquitous nature of biological interactions occurring at different levels of organizations and the paucity of quantitative approaches to understand them, results by our decision-theoretic model represent an initial step towards the deeper understanding of how biological entities interact with each other to drive their evolution.

Ahmen, B. M., **Brandsema, M. J., Bowell, R. A.**, Narayanan, R. M., Howell, S. W., and Dilger, J. M., "Remote sensing performance enhancement due to quantum+ classical cooperative sensor," Radar Sensor Technology XXIV, vol. 11408. International Society for Optics and Photonics, 2020, p. 114080R

Within the last decade, the field of quantum remote sensing has garnered a lot of interest from the radar and communication community. Many papers on this topic have compared the performance of a classical system versus a quantum system. However, the concept of a system using both classical and quantum components in conjunction has not been explored thoroughly. This paper documents the design and simulation of a quantum + classical cooperative remote sensing design in the optical regime. The arrangement uses quantum correlations created by entangled photons in addition to conventional classical waveform correlations. We show that the composite quantum + classical system exhibits increased performance compared to a pure classical system alone.

Brandsema, M. J., Lanzagorta, M., and Narayanan, R. M., "Equivalence of classical and quantum electromagnetic scattering in the far-field regime," IEEE Aerospace and Electronic Systems Magazine, vol. 35, no. 4, pp. 58–73, 2020

Quantum remote sensing, also known as quantum detection and ranging (QUDAR), is the use of entangled photon states to detect targets at a stand-off distance. It inherently relies on sending many single photons through free space, bouncing off of a target and returning to the sensor. It is therefore necessary to understand how single photons interact and scatter from targets of macroscopic size. This article relates quantum and classical scattering in the far-field regime.

Brick, T. R., Mundie, J., Weaver, J., **Fraleigh, R.**, and Oravecz, Z., "Low-burden mobile monitoring, intervention and real-time analysis using the wear-it framework: Example and usability study," JMIR Formative Research, vol. 4, no. 6, p. e16072, 2020

Mobile health (mHealth) methods often rely on active input from participants, for example, in the form of self-report questionnaires delivered via web or smartphone, to measure health and behavioral indicators and deliver interventions in everyday life settings. For short-term studies or interventions, these techniques are deployed intensively, causing nontrivial participant burden. For cases where the goal is long-term maintenance, limited infrastructure exists to balance information needs with participant constraints. Yet, the increasing precision of passive sensors such as wearable physiology monitors, smartphone-based location history, and internet-of-things devices, in combination with statistical feature selection and adaptive interventions, have begun to make such things possible. In this paper, we introduced Wear-IT, a smartphone app and cloud framework intended to begin addressing current limitations by allowing researchers to leverage commodity electronics and real-time decision making to optimize the amount of useful data collected while minimizing participant burden.

Gerg, I. and Monga, V., "Structural Prior Driven Regularized Deep Learning for Sonar Image Classification," in IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1-16, 2022, Art no. 4200416, doi: 10.1109/TGRS.2020.3045649

Deep learning has been recently shown to improve performance in the domain of synthetic aperture sonar (SAS) image classification. Given the constant resolution with a range of SAS, it is no surprise that deep learning techniques perform so well. Despite deep learning's recent success, there are still compelling open challenges in reducing the high false alarm rate and enabling success when training imagery is limited, which is a practical challenge that distinguishes the SAS classification problem from standard image classification set-ups where training imagery may be abundant. We address these challenges by exploiting prior knowledge that humans use to grasp the scene.

Jiang, L. Jiang, **Griffin, C.**, and Wu, R. Wu, "SEGN: Inferring real-time gene networks mediating phenotypic plasticity," Computational and Structural Biotechnology Journal, 2020

The capacity of an organism to alter its phenotype in response to environmental perturbations changes over developmental time and is a process determined by multiple genes that are co-expressed in intricate but organized networks. Characterizing the spatiotemporal change of such gene networks can offer insight into the genomic signatures underlying organismic adaptation, but it represents a major methodological challenge. Here, we integrate the holistic view of systems biology and the interactive notion of evolutionary game theory to reconstruct so-called systems evolutionary game networks (SEGN) that can autonomously detect, track, and visualize environment-induced gene networks along the time axis.

Jiang, L., Liu, X., He, X., Jin, Y., Cao, Y., Zhan, X., **Griffin, C.**, Gragnoli, C., and Wu, R., (2020). "A behavioral model for mapping the genetic architecture of gut-microbiota networks," Gut Microbes, 13(1). https://doi.org/10.1080/19490976.2020.1820847

The gut microbiota may play an important role in affecting human health We develop a computational rule of thumb for addressing this issue by integrating ecological behavioral theory and genetic mapping theory. We introduce behavioral ecology theory to derive mathematical descriptors of how each microbe interacts with every other microbe through a web of cooperation and competition. We estimate the emergent properties of gut-microbiota networks reconstructed from these descriptors and map host-driven mutualism, antagonism, aggression, and altruism QTLs. We further integrate path analysis and mapping theory to detect and visualize how host genetic variants affect human diseases by perturbing the internal workings of the gut microbiota. As the proof of concept, we apply our model to analyze a published dataset of the gut microbiota, showing its usefulness and potential to gain new insight into how microbes are organized in human guts. The new model provides an analytical tool for revealing the "endophenotype" role of microbial networks in linking genotype to end-point phenotypes.

Lennon, R. P., **Griffin, C.**, Miller, E. L., Dong, H., Rabago, D., and Zgierska, A., "Norovirus infections drop 49% in the United States with strict COVID-19 public health interventions," Acta Med Acad. 2020

Norovirus is a substantial burden on the U.S. We compared norovirus outbreaks before and during COVID-19. There were fewer norovirus outbreaks during COVID-19 compared to a similar time period in 2019 (326 versus 638, P<0.001). CONCLUSION: COVID-19 public health interventions may be considered to decrease the burden of norovirus. This demonstrates the ability of more restrictive interventions to decrease other outbreaks of known or emerging viruses.

Murugan, P., Karimi, Y., Squicciarini, A., & **Griffin, C.** (2021). Modeling Longitudinal Behavior Dynamics Among Extremist Users in Twitter Data. In Y. Chen, H. Ludwig, Y. Tu, U. Fayyad, X. Zhu, X. T. Hu, S. Byna, X. Liu, J. Zhang, S. Pan, V. Papalexakis, J. Wang, A. Cuzzocrea, & C. Ordonez (Eds.), Proceedings - 2021 IEEE International Conference on Big Data, Big Data 2021 (pp. 4906-4914). (Proceedings - 2021 IEEE International Conference on Big Data, Big Data 2021). Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/BigData52589.2021.9671644

We use a dynamical systems perspective to analyze a collection of 2.4 million tweets known to originate from ISIS and ISIS-related users. From those users active over a long period of time (i.e., 2+ years), we derive sequences of behaviors and show that the top users cluster into behavioral classes, which naturally describe roles within the ISIS communication structure. We then correlate these classes to the retweet network of the top users showing the relationship between dynamic behavior and retweet network centrality. We use the underlying model to formulate informed hypotheses about the role each user plays. Finally, we show that this model can be used to detect outliers, i.e. accounts that are thought to be outside the ISIS organization but seem to be playing a key communications role and have dynamic behavior consistent with ISIS members.

AWARDS AND HONORS

NERD

JIATFS's NERD Team was awarded the 2021 Federal Executive Board (FEB) Award for the 'Innovation' category by the FEB of South Florida.

The Innovation category recognizes employees in government service that provide a fresh new perspective to interagency programs, products, and/or services.

JIATFS's Named Entity Recognition and Detection (NERD) team, nominated by Jeff Havlicek (JIATFS's J7 Director) consists of Jeff Stahl (JIATFS J7 Deputy Director), and PSU-ARL's State College/Key West engineers/SMEs John O'Hara, Justin Jacobson, Ethan Raymond, Bobby Saunders, and Gabe Moore.

FOOTNOTES

1. Applied Research Laboratory, Penn State University, University Park, PA, USA
2. Departments of Political Science and African American Studies, Penn State University, University Park, PA USA
3. College of Information Science and Technology, Penn State University, University Park, PA USA
4. Department of Family and Community Medicine, Penn State College of Medicine, Hershey, PA USA
5. For examples see:

   Roy M Anderson, T Déirdre Hollingsworth, Rebecca F Baggaley, Rosie Maddren, and Carolin Vegvari. Covid-19 spread in the UK: the end of the beginning? The Lancet, 396(10251):587–590, 2020.

   Riti Bahl, Nicole Eikmeier, Alexandra Fraser, Matthew Junge, Felicia Keesing, Kukai Nakahata, and Lily Reeves. Modeling covid-19 spread in small colleges. Plos one, 16(8):e0255654, 2021.

   Marcia C Castro, Sun Kim, Lorena Barberia, Ana Freitas Ribeiro, Susie Gurzenda, Karina Braga Ribeiro, Erin Abbott, Jeffrey Blossom, Beatriz Rache, and Burton H Singer. Spatiotemporal pattern of covid-19 spread in Brazil. Science, 372(6544):821–826, 2021.

   Duccio Fanelli and Francesco Piazza. Analysis and forecast of covid-19 spreading in China, Italy and France. Chaos, Solitons & Fractals, 134:109761, 2020.

   Michal Wieczorek, Jakub SiŃka, and Marcin Woźniak. Neural network powered covid-19 spread forecasting model. Chaos, Solitons & Fractals, 140:110203, 2020.

   Gang Xie. A novel Monte Carlo simulation procedure for modelling covid-19 spread over time. Scientific reports, 10(1):1–9, 2020.
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