Preview of Award 1934568 - Final Annual Project Report

Cover

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PD/PI Name:	Naoki Saito, Principal Investigator Annamaria B Amenta, Co-Principal Investigator Chen-Nee Chuah, Co-Principal Investigator Thomas Chun Man Lee, Co-Principal Investigator
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Accomplishments

* What are the major goals of the project?

The UC Davis TETRAPODS Institute of Data Science (UCD4IDS)---composed of thirty-five researchers (four PIs and thirty-one senior personnel) coming from four departments (Computer Science, Electrical & Computer Engineering, Mathematics, and Statistics)---will break interdepartmental barriers and promote interdisciplinary research collaborations among faculty members, postdocs, and graduate students. Our project will encourage innovative and robust research, and provide education and mentoring of graduate students and postdocs in data science.
In particular, research at the UCD4IDS will focus on three broad themes: 1) Fundamentals of machine learning directed toward biological and medical applications; 2) Optimization theory and algorithms for machine learning including numerical solvers for large-scale nontrivial learning problems; and 3) High-dimensional data analysis on graphs and networks.
The technical goals of the above themes are: 1) geometric understanding of high-dimensional data, which may allow efficient (re)sampling from manifolds representing certain phenomena of interest and classifying subtle yet critical differences that often appear in biological and medical applications; 2) providing theoretical guarantees and efficient numerical algorithms for non-convex optimization, which is crucial to machine learning; and 3) deepening understanding of how local interactions between individual entities (e.g., neurons) lead to global coordination and decision making.
Students and postdocs engaged in this project will be trained to be the next generation of interdisciplinary data scientists: they will gain deep knowledge of some focused areas, and at the same time, broaden their perspectives in other diverse fields.
The UCD4IDS will bring in the insights gained by the experience of the faculty members in the four primary departments as well as application fields such as neuroscience, medical and health sciences, and veterinary medicine.

* What was accomplished under these goals and objectives (you must provide information for at least one of the 4 categories below)?

Major Activities: * Conducted research; prepared and published some of our results; presented and disseminated some of our results at conferences and seminars

* Organized the concluding UCD4IDS symposium "Foundations of Data Science and Machine Learning" on September 23-24, 2024. It was held in the Physical and Data Sciences Building (PDSB), our new home. Seventy people registered for this symposium. Three external speakers: Dustin Mixon (Ohio State Univ.); Gal Mishne (UCSD); Junwei Lu (Harvard) and four internal speakers: Thomas Strohmer (Math); Krishna Balasubramanian (Stat); Xin Liu (CS); Yubei Chen (ECE) gave excellent and stimulating talks on cutting-edge research in DS/AI. To conclude this symposium, we organized a panel discussion on the future directions of data science and machine learning both in research and education. We invited six panelists: Gal Mishne (UCSD); Patrice Koehl (CS); Junwei Lu (Harvard); Chen-Nee Chuah (ECE); and Thomas Lee (Stat). Their presentations generated heated discussions among participants, and it was an excellent way to conclude this symposium. With the ample space available and new white boards we could also host a poster session. This event clearly demonstrated the usefulness and functionality of the PDSB! Now a number of seminars and research meetings are happening every day.

* Again, initiated quite a number of UC Davis internal collaborations

* Collaborated with two UC Davis groups that engage in data science research and education: the UC Davis DataLab; AI Institute for Next Generation Food Systems (AIFS).

* Organized seminar series related to data science throughout the academic quarters: the Mathematics of Data and Decision at Davis (MADDD) seminars; the Statistics seminars

* Organized annual Joint Mathematics/Statistics Colloquium

* Organized reading seminars on the subjects closely related to the project

* Maintained and constantly updated a website dedicated to our UCD4IDS

* Selected 8 graduate students among our four departments (CS: 1; ECE: 1; Math: 4; Stat: 2) and supported them partially as Graduate Student Researcher. Note that the funding allocations are not uniform among these 8 students; some only received partial summer support while the others received the maximum allowable amount for an academic quarter.

* After a really long delay, we finally purchased a new Mercury GPU 212 Compute Node jointly with the campus High Performance Computing (HPC) Core Facility. More users have been added for the use of the GPU cluster located at the HPC Core Facility.

Specific Objectives:	1) Improve our geometric understanding of high-dimensional data, which may allow efficient (re)sampling from manifolds representing certain phenomena of interest and classifying subtle yet critical differences that often appear in biological and medical applications 2) Investigate and develop data harnessing, feature selection, statistical unsupervised learning, data sampling/streaming methodologies and algorithms 3) Provide theoretical guarantees and efficient numerical algorithms for non-convex optimization, which is crucial to machine learning 4) Investigate private, secure, and on-device machine learning 5) Investigate and develop tools for analyzing hypergraphs, tensors, and high-volume neural data, detecting anomalies/changes over networks, analyzing network structures via random matrix theory, and making cloud-based machine learning more efficient 6) Launch more internal collaborations within our four disciplines 7) Guide graduate students for data science research and education
Significant Results:	The numbering corresponds to that of Specific Objectives section.

1) Koehl (CS) developed a general framework for solving constrained assignment problems using statistical physics ideas, i.e., minimization of a concave free energy parameterized by temperature that captures the constraints. This is expected to be useful for graph data analysis including Web search, neural and social network analysis, gene networks, etc.

Arsuaga (Math/MCB)/Vazquez (Math/MMG) worked on: 1) topological data analysis of cancer genomes: Analysis of the chromosome gains in 5p identified a new gene of interest called PURPL in Luminal A patients; and 2) development of methods to extend h-BiP (their software system) for predicting binding of spike proteins from coronaviruses to human receptors.

De Loera (Math) worked on: Markov Chains that happen inside the set of lattice points of a polyhedron. Examples include Markov chains on graphs that preserve the degree of each vertex. One of the key elements are Markov bases that contain all moves that form the Markov chain.

Polonik (Stat) developed nonparametric regression methods for the case when the true regression function is not necessarily smooth using the fractional Laplacian, proved upper bounds on the in-sample mean-squared estimation error, and provided preliminary empirical results validating the practical performance of the developed estimators.

Rademacher (Math) worked on a weaker form of the Mihail-Vazirani Conjecture (1992), which says that the edge expansion of the graph of a $0/1$ polytope in d-dimension is greater than one over some polynomial function of d, and proved that the edge expansion of the graph of a random $0/1$ polytope is at least $1/12d$ with high probability.

2) Ghiasi (ECE) developed a number of signal processing and machine-learning algorithms that advanced the accuracy of their transabdominal fetal oxygen saturation measurement technology. The algorithms were validated using large scale simulation, as well as in-vivo data obtained from large animal models and human subjects. Studies were approved by UC Davis IACUC and IRB committees, respectively. The algorithms improve signal to noise ratio of sensed data under patient safety constraint, enable more accurate fetal heart tracking, and inference of the latent physiological variable of interest, from non-invasively acquired light intensity measurements.

Fushing (Stat) developed the entropy-based Categorical Exploratory Data Analysis (CEDA) paradigm to algorithmically explore the intricate high-order directional associative relational patterns within the heterogeneous chronic disease dynamics captured by Behavioral Risk Factor Surveillance System (BRFSS) database. This can generate topological individual-risk-landscape that offers profound insights into complex system dynamics and simultaneously exposes atypical subjects as explainable errors across all Machine Learning classifiers.

Lopes (Stat) proposed an approach to inference based on robust max statistics and showed that their distributions can be accurately approximated via bootstrapping when the data are both high-dimensional and heavy-tailed. This theoretical result is complemented by favorable empirical results involving both synthetic data and an application to financial data.

3) Balasubramanian (Stat) developed Zeroth-order Riemannian Averaging Stochastic Approximation (Zo-RASA) algorithms for stochastic optimization on Riemannian manifolds, and showed that Zo-RASA achieves optimal sample complexities for generating epsilon-approximation first-order stationary solutions using only one-sample or constant-order batches in each iteration, provably improved the algorithm's

practicality by using retractions and vector transport, instead of exponential mappings and parallel transports, thereby reducing per-iteration complexity.

4) Chuah (ECE) proposed an develop a geospatially-aware generative model, named MobilityGPT to generate synthetic trajectories that capture human mobility characteristics but remain semantically realistic (including consistent location sequences, etc.).

Zhi (ECE) proposed a novel framework for the so-called federated learning over wireless sensor networks known as UFed-GAN that captures sensor-side data distribution without local classification training and analyzed its convergence and privacy. His experimental results demonstrate the strong potential of UFed-GAN in addressing limited computational resources and unlabeled data while preserving privacy.

Strohmer (Math) worked on the fairness in data science and proposed a rigorous algorithmic framework for fair data representation based on optimal transport, which allows one to estimate the Pareto frontier (i.e., the curve characterizing the optimal tradeoff) between prediction error and statistical disparity. This framework comes with several key advantages, such as computational efficiency as well the ability to preserve data privacy, which were demonstrated by applying it in regression and classification problems.

5) Chaudhuri (Math/NPB) constructed architectures that combine a classic model of neural chaos either with a canonical generative modeling architecture or with energy-based models of neural memory and showed that these architectures have appealing properties for sampling, including easy biologically-plausible control of sampling rates via overall gain modulation.

Chen (Stat) proposed a novel approach aimed at clustering neurons based on their connecting behaviors while accommodating disparities at the neuron level. To this end, he used a dynamic stochastic block model that accommodates unknown time shifts, and established the conditions that guarantee the identifiability of cluster memberships of nodes and representative connecting intensities across clusters. Using methods for shape invariant models, he also proposed computationally efficient semiparametric estimation procedures to simultaneously estimate time shifts, cluster memberships, and connecting intensities, and further applied the proposed method on a motor circuit development data from zebrafish to reveal distinct roles of neurons and identify representative connecting behaviors.

T.Lee (Stat) proposed a new Bayesian framework to detect adversarial examples (called BATer) that uses the randomness of the Bayesian neural network to simulate hidden layer output distribution and leverages the distribution dispersion to detect adversarial examples. Empirical results on several benchmark datasets against popular attacks show that the proposed BATer outperforms the state-of-the-art detectors in adversarial example detection.

Aue/Paul (Stat) studied the problem of testing linear hypotheses under a multivariate regression model with a high-dimensional response and spiked noise covariance. The proposed family of tests consists of test statistics based on a weighted sum of projections of the data onto the estimated latent factor directions, with the weights acting as the regularization parameters. They applied these tests to the Human Connectome Project data to test for the presence of associations between volumetric measurements of human brain and behavioral variables.

	Saito (Math) developed a method to extract explainable features in signal classification problems combining: 1) Scattering Transforms; 2) Logistic Regression Classifier; and 3) Zeroth-Order (or Derivative-Free) Optimization. Previously, it was quite difficult to extract such features and interpret the meaning of the Scattering Transform coefficients due to its nonlinear nature. He coded this method using Julia and used the Adaptive Differential Evolution algorithm as Item 3 above, and extremely encouraging results on synthetic time-series classification problems.
Key outcomes or Other achievements:	6) Launch more internal collaborations within our four disciplines:

During this period the following new collaborations within UC Davis have been initiated by the participants on this grant, which should be considered as key outcomes. Note that we are not listing those already listed in our last year's report.

+ Arsuaga/Vazquez (Math/MCB): with Pranav Pandit (Veterinary School) on ML methods to identify viruses that are potentially infectious to humans; have submitted one grant proposal to the NSF and are planning to submit another proposal to DARPA.

+ Chuah (ECE): with Uma Srivatsa (UCD Health) and Nip Chiamvimonvat (Univ. of Arizona), both from Cardiovascular Medicine, on application of machine learning, deep learning, and causality analysis to multimodal data (ECG/EKG, clinical, metabolisms, EGM & 3DMap for ablation patients) to classify atrial fibrillation (AFib) type, risk of Afib recurrence, and treatment effect.

+ Paul (Stat) with Nina Dörnemann (Stat) on spectral behavior of partial sum processes associated with sample covariance matrices.

+ Paul (Stat) with Jie Peng (Stat) on estimation of covariance matrices of high-dimensional random vectors through determination of latent graphical structures.

+ Saito (Math) with Xin Liu (CS) and Zhaodan Kong (Mechanical & Aeronautical Eng.) on explainable AI methods for time-series data; submitted a joint NSF proposal.

Also during this review period, some of the UCD4IDS members received the following noteworthy awards:

+ Krishna Balasubramanian (Stat), and former faculty member Shiqian Ma (Rice Univ.), and former graduate student Jiaxiang Li (Univ. Minnesota) won 2024 INFORMS Computing Society Prize.

+ Jesús De Loera (Math) won MAA's T. Christine Stevens Award for Leadership Development.

+ Chen-Nee Chuah (ECE) and Mariel Vazquez (Math/MCB) became AAAS fellows.

+ Prem Devanbu (CS) received IEEE's Harlan D. Mills Award.

+ Greg DePaul (Math), our graduate student member, won the Best Presentation Award at EMPOWER 2024 which was held in Institute Pascal, France, Oct. 2024.

+ Jeff Lai (ECE), our former graduate student member, won ECE Best Dissertation -- Anil Jain Memorial Award; in addition, he won 2024 College of Engineering Excellence in Graduate Student Research Award. |

* What opportunities for training and professional development has the project provided?

7) Guide graduate students for data science research and education
* We have organized two regular weekly seminar series throughout the year, i.e.,
The Mathematics of Data and Decisions at Davis (MADDD) seminars and the Statistics Seminars. These seminars are

targeted toward not only faculty experts but also graduate students interested in data science and machine learning. Many of these talks, especially, the MADDD seminar talks, were videotaped and placed on a public website for dissemination purposes.

* We also encouraged and supported our students to attend conferences and give their talks. It is our please to report that 8 talks were delivered by our students. See our Dissemination section for details.

* Many graduate students took online courses and tutorials on data science related subjects, in particular, via some YouTube channels and the online courses provided by various universities.

* UC Davis DataLab, with which we collaborate, provided several useful workshops on programming languages and software tools such as Git, Julia, Python, R, etc. Our graduate students benefited by these.

* Have the results been disseminated to communities of interest? If so, please provide details.

Beyond our publications/other products listed in the Products section, we gave more than 90 seminars and talks during this review period.

Arsuaga (Math/MCB): Mathematical Molecular Biosciences online seminar Oct. 2024
Merida, GEOTOP-A International Conference, Mexico, Jan. 2024
Joint Mathematics Meetings, San Francisco CA, Jan. 2024

Aue (Stat): Virtual Time Series Seminar, Sep. 2023
Recent advances in functional data analysis, Macquarie Univ., Sydney, Australia, Mar. 2024
School of Economics, Univ. of Sydney, Sydney, Australia, Mar. 2024
School of Finance, Actuarial Studies & Statistics, Australian National Univ., Canberra, Australia, Mar. 2024
Statistics Seminar, Colorado State Univ., Fort Collins, CO, Apr. 2024
Statistics Seminar, Columbia Univ., New York, NY, Sep. 2024
Wilks Seminar, ORFE, Princeton Univ., Princeton, NJ, Sep. 2024

Balasubramanian (Stat): Statistics Seminar, Texas A&M Univ., Oct. 2023
Statistics Seminar, Univ. of Waterloo, Canada, Oct. 2023
Statistics Seminar, Univ. of Toronto, Canada, Oct. 2023
Information Theory and Applications (ITA) workshop, San Diego, CA, Feb. 2024
INFORMS Optimization Society Conference, Houston, TX, Mar. 2024
The 25th International Symposium on Mathematical Programming, Montreal, Canada, Jul. 2024

Chaudhuri (Math/NPB): ION Seminar Series, Univ. of Oregon, Oct. 2023
Dynamics Days Conference, UC Davis, Jan. 2024
Lawrence Berkeley National Lab., Mar. 2024
Mathematical Biology Seminar, UC Davis, Apr. 2024

Chen (Stat): 7th International Conference on Econometrics and Statistics, Beijing, China, Jul. 2024
ICSA 2024 Applied Statistics Symposium, Nashville, TN, Jun. 2024
WNAR/IMS/Graybill 2024 Annual Meeting, Colorado State Univ., Fort Collins, CO, Jun. 2024
Biostatistics Seminar, Vanderbilt Univ, Nashville, TN, Dec. 2023
Biostatistics Seminar, UC San Francisco, Oct. 2023

Chuah (ECE): CITRIS Workshop on K12-College STEM Education Partnership – Research Highlight Presentations, Jul. 2023
National Academy of Engineering (NAE) NorCal Symposium, UCD, May, 2024
CITRIS Inspire Future Scientists and Engineers Workshop, Jun. 2024
EMPOWER Workshop, Institut Curie, Paris, France, Oct. 2024 (remote)

De Loera (Math): Conference on Combinatorial Optimization, École des Ponts, Marne-la-Vallée, France, Jul. 2023
SIAM Conference on Applied Algebraic Geometry, Eindhoven Univ. of Technology, the Netherlands, Jul., 2023
Online lecture, Universidad de Nuevo Leon Mexico, Oct. 2023
Merkin Center for Pure and Applied Mathematics, Caltech, Dec. 2023
Workshop on "Mathematics for Artificial Reasoning in Science", Seattle, WA, Apr. 2024

Ding (ECE): Hanoi Univ. of Science and Technology, Hanoi, Vietnam, Sep. 2024
Xiamen Univ., Xiamen, China, Sep. 2024
Southeast Univ., Nanjing, China, Sep. 2024
ICC Tutorial, Denver, CO, Jun. 2024

Drake (Stat): Technical Univ. of Cracow, Poland, Jan. 2024
European Causal Inference Meeting, Univ. of Copenhagen, Denmark, Apr. 2024
European Society for Clinical Biostatistics annual meeting, Thessaloniki, Greece, Jul. 2024

Fannjiang (Math): National Central Univ., Taiwan, Dec. 2023
SIAM Conference on Imaging Sciences, Atlanta, GA, May 2024
SIAM Northern and Central California Sectional Conference, UC Merced, CA, Oct. 2024

Hsieh (Stat): Seminar in Arid Land Research Center, Tottori Univ., Japan, Jul. 2024

Jiang (Stat): Small Area Estimation & Data Science — A Conference Celebrating the 65th Birthday of Prof. Partha Lahiri, Lima, Peru, Jun. 2024
Morris Hansen Lecture, Washington D. C., Nov. 2023

T.Lee (Stat): ICSA International Conference, Hong Kong, China, Jul. 2023
WNAR/IMS/Graybill 2024 Conference, Fort Collins, CO, Jun. 2024
Distinguished Lecture, Chinese Univ. of Hong Kong, China, Jul. 2024
Joint Statistical Meetings, Portland, OR, Aug. 2024

Lopes (Stat): Statistics Colloquium, Univ. of Toronto, Sep. 2024
World Congress of Probability and Statistics, Bochum, Aug. 2024
EcoSta, Beijing, Jul. 2024
Statistics Seminar, Washington Univ. St. Louis, Mar. 2024
CMStatistics, Berlin, Dec. 2023

Paul (Stat): International Symposium on Recent Advances in Theories and Methodologies for Large Complex Data, Tsukuba, Japan, Dec. 2023 (remote)
IMS Asia Pacific Rim Meeting, Melbourne, Australia, Jan. 2024

Polonik (Stat): IMS International Conference on Statistics and Data Science (ICSDS23), Lisbon, Portugal, Dec. 2023
Joint Mathematics Meetings, San Francisco, CA, Jan. 2024
Stochastic Models, Statistics and Their Application, Delft Univ., The Netherlands, Mar. 2024
International Symposium on Nonparametric Statistics, Braga, Portugal, Jun. 2024
Mathematics Seminar, Orsay Univ., Paris, France, Dec. 2023
Institute of Applied Mathematics, Univ. of Heidelberg, Germany, Mar. 2024

Rademacher (Math): One World-MINDS seminar (online), Mar. 2024
GGAM Advisor/Mentor Seminar, UC Davis, Mar. 2024
Probability and Combinatorics seminar, UC Irvine, Mar. 2024
Mathematics colloquium, Case Western Reserve Univ., Sep. 2024

Saito (Math): Joint Mathematics Meetings, San Francisco, CA, Jan. 2024
Applied Math Seminar (online), Florida International Univ., Miami, FL, Apr. 2024
SIAM Imaging Science Conference, Atlanta, GA, May 2024
Graph Signal Processing Workshop, Delft, The Netherlands, Jun. 2024
NSF CompMath PI Meeting, Univ. Washington, Seattle, WA, Jul. 2024

Strohmer (Math): Symposium on Foundations of Data Science and Machine Learning, UC Davis, Sep. 2024
NSF CompMath PI Meeting, Univ. Washington, Seattle, Jul. 2024
Mathematics Colloquium, UC Santa Barbara, May 2024
Digital Health and AI Symposium, UC Davis Health, Apr. 2024
WACV Tutorial on AI Governance and Data Protection for Computer Vision and Beyond. Hawaii, Jan. 2024
Mathematics Colloquium, UPenn, Nov. 2023

Mathematics of Machine Learning Seminar, UMass Amherst, Nov. 2023
CMSE Seminar, Michigan State Univ. Oct. 2023

Graduate Students:

Chen (Math): INFORMS Optimization Society Conference, Houston, TX, Mar. 2024
International Symposium on Mathematical Programming, Montreal, Canada, Jul. 2024

DePaul (Math): SIAM Conference on Mathematics of Data Science, Atlanta, GA, Oct. 2024
EMPOWER 2024, Institute Pascal, Saclay, France, Oct. 2024
Spectra Survey of Mathematics Conference, Ohio State Univ., Apr. 2024
GEOTOP-A International Conference, Mérida (Yucatán), México, Jan. 2024
Joint Mathematics Meetings, San Francisco, Jan. 2024
Apprenticeship Week: Varieties from Statistics, Univ. of Chicago, Oct. 2023

Dissemination effort other than talks:
Saito (Math) has maintaining the UCD4IDS GitHub website, which currently lists 15 open-source software packages including his own packages.

Koeppe (Math) has been the lead developer of SageMath, an open source mathematical system that has become important in data science.

Strohmer (Math) co-organized the following three meetings: 1) BIRS Workshop "Computational Harmonic Analysis in Data Science and Machine Learning," Oaxaca, Mexico, Sep. 2024; 2) Conference More on Harmonic Analysis, Strobl, Austria, Jun. 2024; 3) Mathematical Information Science Workshop, Lagrange Center, Paris France, Oct. 2023.

Vazques (Math/NCB) co-organized: 1) BIRS workshop "The Crossroads of Topology, Combinatorics and Biosciences: Deciphering the Entanglement of Multi-Stranded Nucleic Acids", Banff, Canada, Mar. 2024; and 2) a mini-course on "Applied Topology: DNA Topology" and the special session on "Applied Topology: DNA topology, Material Science, Topological Data Analysis", the Canadian Mathematical Society Summer Meeting, Saskatoon, Canada, Jun. 2024.

Products

Books

Book Chapters

Inventions

Journals or Juried Conference Papers
View all journal publications currently available in the [NSF Public Access Repository](#) for this award.

The results in the NSF Public Access Repository will include a comprehensive listing of all journal publications recorded to date that are associated with this award.

Adamopoulos, Iannis E and Kim, Ki-Jo and Tagkopoulos, Ilias and Kim, Minseung. (2019). Compendium of synovial signatures identifies pathologic characteristics for predicting treatment response in rheumatoid arthritis patients. *Clinical Immunology*. 202 (C) 1 to 10. Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Saito, on 08/09/2020) Full text   Citation details

Pivetti, Christopher and Ghiasi, Soheil and Fong, Daniel D. and Galganski, Laura and Lee Farmer, Diana and Vali, Kourosh and Yamashiro, Kaeli and Johnson, M. Austin and Hedriana, Herman L.. (2020). 98: Validation of a novel transcutaneous fetal oximeter in a hypoxic fetal sheep model. *American Journal of Obstetrics and Gynecology*. 222 (S) S80. Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Saito, Naoki on 08/11/2020) Full text   Citation details

Fong, Daniel D. and Neff, Lucas and Lee Farmer, Diana and Johnson, M. Austin and Stephenson, Jacob and Hirose, Shinjiro and Yamashiro, Kaeli and Galganski, Laura and Williams, Timothy and Ghiasi, Soheil. (2020). 1168: Fetal tolerance of maternal resuscitative endovascular balloon occlusion of the aorta in a sheep model. *American Journal of Obstetrics and Gynecology*. 222 (S) S718 to S719. Status = Added in NSF-PAR

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Li, Weilin and Liao, Wenjing and Fannjiang, Albert. (2020). Super-resolution limit of the ESPRIT algorithm. *IEEE Transactions on Information Theory*. 1 to 1. Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Saito, Naoki on 08/09/2020) Full text   Citation details

Nadakuditi, Raj Rao and Prasadan, Arvind and Paul, Debashis. (2020). Sparse equisigned PCA: Algorithms and performance bounds in the noisy rank-1 setting. *Electronic Journal of Statistics*. 14 (1) 345 to 385. Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Saito, Naoki on 08/09/2020) Full text   Citation details

Lee, Thomas C. and Wong, Raymond K. and Su, Yi. (2020). Network estimation via graphon with node features. *IEEE Transactions on Network Science and Engineering*. 1 to 1. Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Lee, on 07/13/2021) Full text   Citation details

Zou, Hui and Ma, Shiqian and Xue, Lingzhou and Chen, Shixiang. (2020). An Alternating Manifold Proximal Gradient Method for Sparse Principal Component Analysis and Sparse Canonical Correlation Analysis. *INFORMS Journal on Optimization*. ijoo.2019.0032. Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Saito, Naoki on 08/10/2020) Full text   Citation details

Chen, Pengwen and Fannjiang, Albert. (2020). Blind ptychography: uniqueness and ambiguities. *Inverse Problems*. 36 (4) 045005. Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Saito, Naoki on 08/09/2020) Full text   Citation details

Fannjiang, Albert and Zhang, Zheqing. (2020). Fixed Point Analysis of Douglas--Rachford Splitting for Ptychography and Phase Retrieval. *SIAM Journal on Imaging Sciences*. 13 (2) 609 to 650. Status = Added in NSF-PAR

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Dette, Holger and Aue, Alexander and Kokot, Kevin. (2020). Functional data analysis in the Banach space of continuous functions. *Annals of Statistics*. 48 (2) 1168 to 1192. Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Saito, Naoki on 08/09/2020) Full text   Citation details

Rai, Navneet and Kim, Minseung and Eetemadi, Ameen and Schmitz, Harold and Tagkopoulos, Ilias and Pereira, Beatriz Merchel. (2020). The Computational Diet: A Review of Computational Methods Across Diet, Microbiome, and Health. *Frontiers in Microbiology*. 11 . Status = Added in NSF-PAR

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Chen, Xin Luigi and Kuhn, Brooks T. and Cortes-Puch, Irene and Chuah, Chen-Nee and Rehm, Gregory B. and Adams, Jason Y. and Anderson, Nicholas R. and Woo, Sang Hoon. (2020). Leveraging IoTs and Machine Learning for Patient Diagnosis and Ventilation Management in the Intensive Care Unit. *IEEE Pervasive Computing*. 19 (3) 68 to 78. Status = Added in NSF-PAR

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Lai, Zhengfeng and Hu, Zin and Dugger, Brittany N. and Xu, Wenda and Guo, Runlin and Mifflin, Kelsey and Chuah, Chen-Nee and Cheung, Sen-ching. (2020). Automated grey and white matter segmentation in digitized Aβ human brain tissue slide images. *2020 IEEE International Conference on Multimedia & Expo Workshops (ICMEW)*. 1 to 6. Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Saito, Naoki on 08/09/2020) Full text   Citation details
Wang, Sheng and Deng, Qi and Wang, Xiong and Ren, Jing and Xu, Shizhong and Malboubi, Mehdi and Chuah, Chen-Nee. (2020). The Joint Optimization of Online Traffic Matrix Measurement and Traffic Engineering For Software-Defined Networks. *IEEE/ACM Transactions on Networking*. 28 (1) 234 to 247. Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Saito, Naoki on 08/09/2020) Full text   Citation details

Elliott, Jonathan and De Meyer, Geert and Bradley, Richard and Panagiotakos, Theodoros and Kennedy, James and Kim, Minseung and Tagkopoulos, Ilias and Kokkinos, Yiannis and Watson, Phillip. (2019). Predicting early risk of chronic kidney disease in cats using routine clinical laboratory tests and machine learning. *Journal of Veterinary Internal Medicine*. 33 (6) 2644 to 2656. Status = Added in NSF-PAR

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Tagkopoulos, Ilias and Simmons, Gabriel and Lemay, Danielle G. and Chin, Elizabeth L. and Kan, Annie and Bouzid, Yasmine Y. and Burnett, Dustin J.. (2019). Nutrient Estimation from 24-Hour Food Recalls Using Machine Learning and Database Mapping: A Case Study with Lactose. *Nutrients*. 11 (12) 3045. Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Saito, Naoki on 08/09/2020) Full text   Citation details

Pereira, B. and Wang, X. and Tagkopoulos, I. (2020). Short- and Long-Term Transcriptomic Responses of Escherichia coli to Biocides: a Systems Analysis. *Journal of applied environmental microbiology*. 86 e00708-20. Status = Added in NSF-PAR

Federal Government's License = Acknowledged. (Completed by Saito, Naoki on 08/09/2020) Full text   Citation details

Eetemadi, Ameen and Parker-Graham, Christine A. and Loeher, Malina and Soto, Esteban and Yazdi, Zeinab and Marshman, Blythe C. and Moore, James D. and Barnum, Samantha and Richey, Christine A.. (2020). Effect of oxytetracycline treatment on the gastrointestinal microbiome of critically endangered white abalone (Haliotis sorenseni) treated for withering syndrome. *Aquaculture*. 526 (C) 735411. Status = Added in NSF-PAR

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Rojas, Carlos and Amenta, Nina. (2020). Dihedral deformation and rigidity. *Computational Geometry*. 90 (C) 101657. Status = Added in NSF-PAR

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Contextually aware fetal sensing in transabdominal fetal pulse oximetry . *Patent No. US16/820,388* . UNITED STATES. Application Date = 03/16/2020 .   Status = Pending

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Websites or Other Internet Sites

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Saito, Naoki	PD/PI	4
Amenta, Annamaria	Co PD/PI	0
Chuah, Chen-Nee	Co PD/PI	1
Lee, Thomas Chun Man	Co PD/PI	1
Arsuaga, Javier	Faculty	1
Aue, Alexander	Faculty	1
Balasubramanian, Krishna	Faculty	1
Burman, Prabir	Faculty	0
Chaudhuri, Rishidev	Faculty	1
Chen, Shizhe	Faculty	1
De Loera, Jesus	Faculty	1
Devanbu, Premkumar	Faculty	1
Ding, Zhi	Faculty	0
Drake, Christiana	Faculty	0
Fannjiang, Albert	Faculty	3
Ghiasi, Soheil	Faculty	1
Hass, Joel	Faculty	0
Hsieh, Fushing	Faculty	1
Jiang, Jiming	Faculty	1
Koehl, Patrice	Faculty	1
Koeppe, Matthias	Faculty	1
Lai, Lifeng	Faculty	1
Le, Can	Faculty	1
Lopes, Miles	Faculty	1

Name	Most Senior Project Role	Nearest Person Month Worked
Paul, Debashis	Faculty	1
Polonik, Wolfgang	Faculty	1
Rademacher, Luis	Faculty	1
Rajaratnam, Balakanapathy	Faculty	1
Strohmer, Thomas	Faculty	1
Tagkopoulos, Ilias	Faculty	1
Vazquez, Mariel	Faculty	1
Chen, Xuxing	Graduate Student (research assistant)	3
DePaul, Gregory	Graduate Student (research assistant)	6
Du, Wei	Graduate Student (research assistant)	3
Godkin, Benjamin	Graduate Student (research assistant)	1
Halev, Avishai	Graduate Student (research assistant)	3
Weicht, Tait	Graduate Student (research assistant)	0
Wijesinghe, Achintha	Graduate Student (research assistant)	2
Zhang, Zitong	Graduate Student (research assistant)	3
Schonsheck, Stefan	Consultant	0

Full details of individuals who have worked on the project:

Naoki Saito
Email: saito@math.ucdavis.edu
Most Senior Project Role: PD/PI
Nearest Person Month Worked: 4

Contribution to the Project: Coordinated and managed almost all the activities of the UCD4IDS; Co-organized a symposium "Foundations of Data Science and Machine Learning" (Sep. 2024); Maintained the dedicated UCD4IDS website as well as its GitHub.com site; Conducted research; Supervised three Ph.D. students, and four undergraduate students; Gave presentations on our research and projects at various conferences and seminars.

Funding Support: NSF Grant DMS-1912747; NSF Grant IIS-1631329; NSF RTG Grant DMS-1148643; ONR Grant N00014-20-1-2381

Change in active other support: No

International Collaboration: No
International Travel: No

Annamaria B Amenta
Email: amenta@cs.ucdavis.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 0

Contribution to the Project: Conducted research; attended seminars; participated in the Steering Committee meeting

Funding Support: None

Change in active other support: No

International Collaboration: No
International Travel: No

Chen-Nee Chuah
Email: chuah@ucdavis.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Conducted research; supervised postdocs and graduate students; attended seminars; served as a panelist for the panel discussions at our symposium "Foundations of Data Science and Machine Learning".

Funding Support: * Grant from The Center for Women's Cardiovascular and Brain Health * Statewide Transportation Research Program UC-ITS grant

Change in active other support: Yes

International Collaboration: No
International Travel: No

Thomas Chun Man Lee
Email: tcmlee@ucdavis.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Conducted research; supervised graduate students and a postdoc; attended seminars; served as a panelist of the roundtable discussion at our symposium "Foundations of Data Science and Machine Learning".

Funding Support: None

Change in active other support: No

International Collaboration: No
International Travel: No

Javier Arsuaga
Email: jarsuaga@math.ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Oversaw and designed studies; ensured the integrity of the research; mentored students and researchers; prepared manuscripts; worked on some experiments required for the COVID-19 project.

Funding Support: NSF grants: DMS-1854770; DMS-2054321

International Collaboration: No
International Travel: No

Alexander Aue
Email: aaue@ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Conducted research; supervised graduate students and a postdoc; attended seminars; served as a member of the Steering Committee

Funding Support: None

International Collaboration: No
International Travel: No

Krishna Balasubramanian
Email: kbala@ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Conducted research; supervised graduate students and a postdoc; attended seminars; gave a talk at our symposium.

Funding Support: NSF Grant DMS-2053918

International Collaboration: No
International Travel: No

Prabir Burman
Email: pburman@ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 0

Contribution to the Project: Conducted research; co-supervised a graduate student in Biostatistics (Maxime Pouokam); attended seminars.

Funding Support: None

International Collaboration: No
International Travel: No

Rishidev Chaudhuri
Email: rchaudhuri@ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Conducted research; supervised graduate students; attended seminars.

Funding Support: NSF CRCNS 2207895; UC Davis Planning Grant for Large Interdisciplinary Applications in Neuroscience (LIAN); Sloan Research Fellowship FG-2021-16304; Air Force Office of Scientific Research FA9550-22-1-0532; Navy Office of Naval Research N000142412325

International Collaboration: No
International Travel: No

Shizhe Chen
Email: szdchen@ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Conducted research; supervised graduate and undergraduate students; attended seminars

Funding Support: NSF DMS-1916476

International Collaboration: No
International Travel: No

Jesus De Loera
Email: deloera@math.ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Conducted research; supervised graduate students; attended seminars; participated in the roundtable discussions, helped prepare a new grant for renewal, was active as steering committee member and looking at funding for Math/Applied Math students; Co-organized the closing scientific event of the grant ``Foundations of Data Science and Machine Learning''.

Funding Support: NSF DMS-1818969

International Collaboration: No
International Travel: No

Premkumar Devanbu
Email: ptdevanbu@ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Supervised graduate students; attended seminars; participated in the roundtable discussions. Gave tutorial lectures on the use of Docker Containers in Scientific research in some settings.

Funding Support: NSF grants: 1414172; 2107592. A grant from Sandia National Laboratories.

International Collaboration: No
International Travel: No

Zhi Ding
Email: zding@ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 0

Contribution to the Project: Conducted research; supervised graduate students; attended seminars; joint work with student and post-doctoral researchers to draft and revise manuscripts for publications; served as a member of the Steering Committee

Funding Support: None

International Collaboration: Yes, Taiwan
International Travel: No

Christiana Drake
Email: cmdrake@ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 0

Contribution to the Project: Conducted research; supervised graduate students; attended seminars

Funding Support: CA Dept. Transportation grant 65A0686; US Dept. Veterans Affairs grant 1BX004423-01A1

International Collaboration: No
International Travel: No

Albert Fannjiang
Email: fannjiang@math.ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 3

Contribution to the Project: Conducted research; supervised graduate students; attended seminars.

Funding Support: Simons Foundation Grant FDN 2019-24

International Collaboration: Yes, Taiwan
International Travel: No

Soheil Ghiasi
Email: ghiasi@ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Conducted research; supervised graduate students; attended seminars.

Funding Support: NSF IIS-1838939; NIH grant P41EB032840

International Collaboration: No
International Travel: No

Joel Hass
Email: hass@math.ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 0

Contribution to the Project: Conducted research; attended seminars

Funding Support: BSF grant 2018313

International Collaboration: No
International Travel: No

Fushing Hsieh
Email: fhsieh@ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Conducted research; supervised graduate students; attended seminars

Funding Support: None

International Collaboration: No
International Travel: No

Jiming Jiang
Email: jimjiang@ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Conducting research; Supervising graduate students; Attended seminars

Funding Support: DMS-2210569

International Collaboration: No
International Travel: No

Patrice Koehl
Email: pakoehl@ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Conducted research; supervised graduate students; attended seminars; served as a member of the Steering Committee; served as a panelist in the panel discussion at our symposium.

Funding Support: NSF grant DMS-1760485

International Collaboration: No
International Travel: No

Matthias Koeppe
Email: mkoeppe@math.ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Developed software; conducted research; supervised graduate students; organized MADDD seminars.

Funding Support: NSF DMS-2012764

International Collaboration: No
International Travel: No

Lifeng Lai
Email: lflai@ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Conducted research; supervised graduate students; attended seminars

Funding Support: None

International Collaboration: No
International Travel: No

Can Le
Email: canle@ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Conducted research; supervised graduate students; attended seminars

Funding Support: NSF grant DMS-2015134

International Collaboration: No
International Travel: No

Miles Lopes
Email: melopes@ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Conducted research; attended seminars.

Funding Support: DOE grant DE-SC0023490

International Collaboration: No
International Travel: No

Debashis Paul
Email: debpaul@ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Conducted research; supervised graduate students; attended seminars.

Funding Support: NSF grant DMS-1915894

International Collaboration: No
International Travel: No

Wolfgang Polonik
Email: wpolonik@ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Conducted research; supervised graduate students; attended seminars.

Funding Support: None

International Collaboration: No
International Travel: No

Luis Rademacher
Email: lrademac@math.ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Conducted research; supervised graduate students; attended seminars

Funding Support: NSF CCF-2006994

International Collaboration: No
International Travel: No

Balakanapathy Rajaratnam
Email: brajaratnam@ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Conducted research; upervised graduate students; attended seminars; involved in curriculum development.

Funding Support: NSF DMS-1916787

International Collaboration: No
International Travel: No

Thomas Strohmer
Email: strohmer@math.ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Conducted research; supervised graduate students; attended seminars; gave a talk at our symposium.

Funding Support: NSF-DMS-2027248; NSF DMS-2208356; P41EB032840; NIH-R01HL16351

International Collaboration: No
International Travel: No

Ilias Tagkopoulos
Email: itagkopoulos@ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Conducted research; supervised graduate students; attended seminars.

Funding Support: NSF/USDA/NIH grants

International Collaboration: No
International Travel: No

Mariel Vazquez
Email: mariel@math.ucdavis.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Conducted research pertaining to Theme 1a: Geometry of Data. Supervised graduate and undergraduate students; attended seminars; applied for extramural funding. Gave plenary lectures on results of my research, noteworthy is the SIAM invited address at the 2024 Joint Math Meetings.

Funding Support: NSF DMS/NIGMS-2054347

International Collaboration: No
International Travel: No

Xuxing Chen
Email: xuxing@math.ucdavis.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Conducted research; attended seminars

Funding Support: None

International Collaboration: No
International Travel: No

Gregory DePaul
Email: gdepaul@ucdavis.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

Contribution to the Project: Conducted research

Funding Support: Cardiac Signaling Lab (UC Davis)

International Collaboration: No
International Travel: No

Wei Du
Email: wedu@ucdavis.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Conducted research, finished 3 manuscripts and attended seminars

Funding Support: None

International Collaboration: No
International Travel: No

Benjamin Godkin
Email: bmgodkin@ucdavis.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Conducted research

Funding Support: None

International Collaboration: No
International Travel: No

Avishai Halev
Email: ahalev@math.ucdavis.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Conducted research

Funding Support: None

International Collaboration: No
International Travel: No

Tait Weicht
Email: weicht@math.ucdavis.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 0

Contribution to the Project: Conducted research; attended seminars

Funding Support: None

International Collaboration: No
International Travel: No

Achintha H. Wijesinghe
Email: achwijesinghe@ucdavis.edu

Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 2

Contribution to the Project: Conducted research; attended seminars

Funding Support: None

International Collaboration: No
International Travel: No

Zitong Zhang
Email: zztzhang@ucdavis.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Conducted research; attended seminars

Funding Support: NSF DMS-1916476

International Collaboration: No
International Travel: No

Stefan C. Schonsheck
Email: scschonsheck@ucdavis.edu
Most Senior Project Role: Consultant
Nearest Person Month Worked: 0

Contribution to the Project: Co-authored a paper with the PI.

Funding Support: None

International Collaboration: No
International Travel: No

What other organizations have been involved as partners?
Nothing to report.

Were other collaborators or contacts involved? If so, please provide details.
Nothing to report

Impacts

What is the impact on the development of the principal discipline(s) of the project?

The theory, algorithms, and software tools that have been and are being developed will be likely to make a positive impact in solving practical data analysis and machine learning problems in our core disciplines, i.e., computer science (analyzing social networks and website links); electrical engineering (monitoring and controlling sensor networks); mathematics (nonconvex optimization theory and algorithms; data analysis on higher-order graphs); and statistics (inverse problems, statistical graph and network analysis).

What is the impact on other disciplines?

Our research and development above will also be likely to make a positive impact on other disciplines, e.g., civil engineering (monitoring traffic flow on a road network); biology and medicine (analyzing data measured on real neural networks, detecting

changes in the brain structures due to diseases, imaging live biological cells for analyzing their growth, real-time monitoring of health of fetuses, privacy-protected medical diagnostics); agriculture and veterinary medicine (monitoring and improving milk reproduction management), etc.

What is the impact on the development of human resources?

Through this project, many of our students have become familiar with data obtained from scientists in the different fields such as neuroscience, biomedical engineering, medicine, environmental sciences, and anthropology, etc. Also, through the weekly Mathematics of Data and Decision at Davis (MADDD) seminars, the weekly Statistics seminars, and the annual Joint Mathematics/Statistics Colloquia, students in each of our four departments had opportunities to get to know the students from the other three departments better. In addition, they had opportunities to meet and discuss with invited speakers from industry to hear their experience in industry and what kind of knowledge and skills are expected in industry.

What was the impact on teaching and educational experiences?

We believe that we, as a group of 35 faculty members, have influenced on the major decision of our campus: we started offering Data Science Undergraduate Major degrees in Fall 2022! The curriculum for this DS major degree is organized into four initial tracks: 1) Foundations; 2) Agricultural and Environmental Sciences; 3) Biological Sciences; and 4) Social Sciences. Then, majors in every track will receive ethics training as well as some foundational courses in CS, Math, and Stat, e.g., MAT 19 sequence (Calculus for Data-Driven Applications). About 120 students enroll as DS major every year, totaling about 500 undergraduate students eventually.

What is the impact on physical resources that form infrastructure?

The project contributed the campus-wide High Performance Computing (HPC) Core Facility for their GPU purchase. As we reported in the Major Activities section, more than 30 members of the UCD4IDS created their CPU/GPU cluster accounts at the HPC Core Facility, and started running their jobs on the currently available GPUs. Also, we finally helped HPC Core Facility to purchase a new Mercury GPU 212 Compute Node.

What is the impact on institutional resources that form infrastructure?

UC Davis administration has allocated space for our activities in the first and ground floors of the Physical Sciences and Engineering Library. The building renovation was completed for this purpose in December 2023, and we started using this building (renamed as Physical and Data Sciences Building) for various meetings on data sciences and machine learning. PI and a member of the Steering Committee moved their offices to this new building.

What is the impact on information resources that form infrastructure?

Our GitHub.com website, https://github.com/UCD4IDS/, currently lists 15 open-source software packages. Some of our packages, e.g., sage, ContinuousWavelets.jl, and WaveletsExt.jl have been quite popular.

What is the impact on technology transfer?
Nothing to report.

What is the impact on society beyond science and technology?
Nothing to report.

What percentage of the award's budget was spent in a foreign country?
Nothing to report.

Changes/Problems

Changes in approach and reason for change
Nothing to report.

Actual or Anticipated problems or delays and actions or plans to resolve them
Nothing to report.

Changes that have a significant impact on expenditures
Nothing to report.

Significant changes in use or care of human subjects
Nothing to report.

Significant changes in use or care of vertebrate animals
Nothing to report.

Significant changes in use or care of biohazards
Nothing to report.

Change in primary performance site location
Nothing to report.