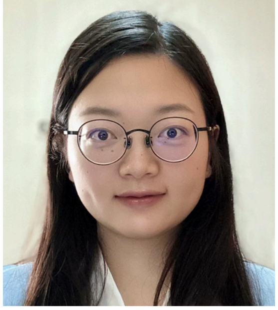
RESEARCH

Inside IISE Journals

This month, we spotlight two articles from the upcoming special issue on Federated Distributed Learning and Analytics to appear in *IISE Transactions* (Vol. 57, No. 7). These articles showcase how federated learning advances information exchange and causal discovery across distributed industrial systems while preserving data privacy. The first article presents a novel data analytics method for discovering nonlinear causal relationships across distributed systems while preserving data privacy. Addressing the limitations of traditional Bayesian networks in causal analysis, the authors propose a two-step, federated multitask learning approach that enables each system to model its local nonlinear causal structures within its database. Meanwhile, a central server aligns these structures collaboratively without accessing raw data to discover global causal structures. The method demonstrates high accuracy while ensuring strong privacy protection. This research offers a powerful solution for collaborative causal discovery in privacy-sensitive domains such as distributed manufacturing systems. The second article addresses the challenge of secure information exchange for collaborative data analysis among organizations while preserving individual privacy. The proposed algorithms are built on differential privacy, enabling the addition of controlled noise to the shared data to ensure confidentiality. Validated using real-world energy consumption data from U.S. power grids and German households, as well as clinical trial data from multiple healthcare centers, the approach demonstrates improved accuracy in data analytics. This research represents a significant advancement in privacy-preserving collaborative learning, providing a robust solution for data analytics when direct data sharing is restricted.

Tian Lan

Ben Niu



Xing Yang

Chen Zhang

Learning causality across systems, together and apart: A federated thinking

Understanding not just what is correlated, but why things happen – uncovering true cause-effect relationships across variables – is essential for understanding system behavior and enabling informed decision-making. Bayesian networks, which represent variable connections through directed acyclic graphs, have emerged as powerful tools for modeling their causal effects. However, most traditional Bayesian networks typically assume linear dependencies between variables, which may oversimplify the complex, nonlinear dynamics present in many real-world systems.

In real-world industrial environments, relevant data are often distributed across multiple systems or organizations, each capturing different yet related variables under varying conditions. Although combining these datasets could significantly improve causal analysis, privacy, regulatory and proprietary concerns often render direct data sharing infeasible. Federated learning has emerged as a solution for integrating diverse datasets while preserving data privacy. The challenge involves discovering causal relationships across systems with both overlapping and distinct variables without compromising data confidentiality.

To address these challenges, researchers Xing Yang and Ben Niu from Shenzhen University, together with Tian Lan and Chen Zhang from Tsinghua University, propose a new approach that integrates nonparametric causal modeling with federated multitask learning. Their method enables the discovery of nonlinear causal relationships across distributed datasets – without exposing raw data.

In this approach, each system models its local Bayesian network with smooth basis functions that flexibly capture nonlinear causal patterns within its own dataset. A central server then coordinates the learning process by aligning causal structural similarities across systems. This two-step optimization process facilitates the collaborative discovery of global causal insights while maintaining tailored models for each system's specific variable set and ensuring strict data privacy.

The proposed approach demonstrates superior performance in both accuracy and data privacy protection, as evidenced by simulations and a real-world case study of a three-phase flow facility. This work presents a powerful approach for collaborative, privacy-preserving causal discovery across complex, distributed systems.

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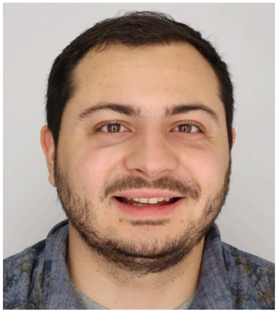
Privacy-preserving information exchange for collective inference and learning

How can companies share and analyze data collectively while complying with privacy regulations? Can smart grids, healthcare systems and financial institutions exchange information without violating their obligations to protect the privacy of their customers, patients, clients, and other individuals? How can we effectively reconcile individual privacy and data security requirements with the goals of collective decision-making and learning?

Understanding the tradeoffs between data privacy and utility in collective learning scenarios is critical to designing efficient learning systems that balance accurate decision making and individual privacy.

In their *IISE Transactions* paper, "Privacy-Preserving Distributed Estimation and Learning," Marios Papachristou, Ph.D. candidate at Cornell University, and Amin Rahimian, assistant professor of Industrial



Marios Papachristou

Amin Rahimian

Engineering at the University of Pittsburgh, emphasize the relevance of these challenges to the energy sector, where emerging net metering technologies in smart grids need to support distributed energy generation; for example, to compensate customers for rooftop solar while protecting consumer data. Sharing detailed energy consumption data in this case can pose significant privacy and security risks, such as revealing when someone is at home, their daily commute, online habits, family illnesses and so on.

The authors have developed algorithms to estimate statistical properties of private signals that are distributed across a network of agents. For example, agents may represent different households, signals may reflect net metering measurements, and the goal is to estimate the average power consumption for optimal pricing. Their approach builds on the paradigm of differential privacy, a widely used framework that protects individual data by adding controlled noise to shared information. Their designed algorithms can adjust noise levels based on the variability of the private signals and the communication patterns among agents.

To test their approach, they applied it to real-world energy consumption datasets collected from power grids in the U.S. and households in Germany. They demonstrated that their methods not only maintain privacy but also produce accurate results efficiently, outperforming conventional approaches that use differential privacy with federated learning.

In a follow-up work, "Differentially Private Distributed Inference," Papachristou and Rahimian study similar tradeoffs for inference in discrete spaces, particularly for distributed hypothesis testing such as in a multicenter clinical trial. In that case, multiple health centers collaborating on a clinical trial face privacy risks for their patient data. Without reliable privacy guarantees, their data sharing and analytics would require complex legal agreements to comply with healthcare privacy regulations, such as HIPAA.

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This month, we highlight two articles from *IISE Transactions on Occupational Ergonomics and Human Factors* (Volume 13, No. 1), a special issue on emerging hardware and software technologies for assessing and improving occupational safety and health. In the first, Strawderman and colleagues showed that an organization's safety culture is paramount to reducing hesitancy toward wearable device acceptance in manufacturing. Martinez, et al., in the second article evaluated four occupational exoskeletons using universal design principles and found significant design limitations during assembly and donning tasks that could prevent equitable use by diverse worker populations.

Study provides insights to reduce hesitancy in adopting wearables in workplace

Wearable technology is well integrated into most people's daily lives. Smartwatches, health trackers and even jewelry embedded with sensor technology are used by many people to meet their own health-related goals. As wearable technology becomes more embedded in society, why do we not see its use increasing in manufacturing settings?

Ergonomists and industrial engineers often look to technology to improve workplace outcomes such as safety and productivity. However, hesitancy toward new technology can hinder the adoption of devices such as wearables. These themes are explored further in the paper entitled "Wearable Technology Hesitancy in Industrial Applications."

In their study, Lesley Strawderman, Bailey Jose, Reuben Burch, David Saucier, Ayush Poudel and Brian Smith from Mississippi State University spoke to industry representatives about the factors that influence the implementation of wearables in the manufacturing workplace. They specifically wanted to learn why wearables were not commonplace for tracking and predicting ergonomics, safety and productivity outcomes. After all, if a person is using a wearable device most days, why not leverage that for improving work outcomes?

Given the situation in most manufacturing plants, where the user of a wearable device is not the chooser of the device, they focused on high-level hesitancy factors related to management, work design and job requirements. This contrasts with most technology acceptance literature that explores individual factors such as comfort and usability.

The team completed 14 focus groups with employers, technology providers, workforce strategists, occupational safety professionals, workers (incumbent and in training)

Authors of the study on wearable technology included, from left, David Saucier, Reuben Burch, Lesley Strawderman and Brian Smith of Mississippi State University.

and state agency workforce administrators. Focus group participants provided several actionable insights to reduce hesitancy in adopting wearables in the industrial workplace. First, emphasizing safety culture and the benefits to workplace safety and health is paramount. Second, the case for using wearable for performance improvement should also be discussed after leading with safety. Finally, organizations should consider voluntary participation in a wearables program with early adopters.

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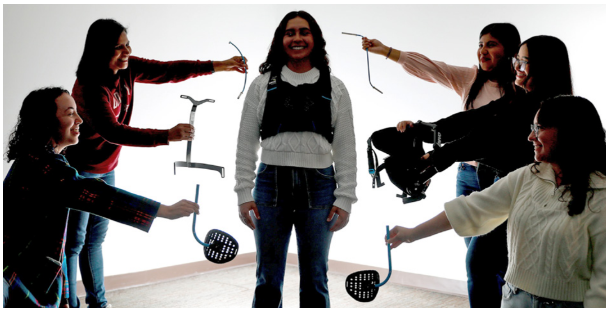
Heuristic evaluations of exoskeletons using universal design principles

A paper, "Heuristic Evaluations of Back-Support, Shoulder-Support, Handgrip-Strength Support, and Sit-Stand-Support Exoskeletons Using Universal Design Principles" by Alejandra Martinez, Laura Tovar, Carla Irigoyen Amparan, Karen Gonzalez, Prajina Edayath, Priyadarshini Pennathur and Arunkumar Pennathur from the Physical, Information and Cognitive Human Factors Engineering Research Laboratory at the University of Texas at El Paso, addresses a critical gap in exoskeleton research. While occupational exoskeletons show promise for reducing musculoskeletal injuries in industrial settings, the design of these technologies often overlook universal usability.

In their study, the authors included seven evaluators who assessed four commercially available exoskeletons – back support, shoulder support, handgrip-strength support and sit-stand support) during assembly, donning, doffing and disassembly tasks. Their results indicated important design limitations, particularly during assembly and donning phases, which accounted for 76% of universal design violations.

Key concerns included inadequate information feedback, poor accessibility for diverse users and lack of intuitive design. The authors further found that assembly required substantial strength, dexterity and balance that could exclude workers with disabilities, while safety concerns were prevalent during donning tasks.



Photos provided by the authors

Researchers from the University of Texas at El Paso investigated the universal usability of four commercially available exoskeletons.

For wider industrial adoption, exoskeleton designers must consider broader user populations, particularly as labor force data indicates a growing presence of workers with disabilities, aging workers and women in industrial settings. Future designs should prioritize simplified operation, improved safety features and accessibility. This research provides valuable insights for creating more inclusive exoskeletons that could transform workplaces and reduce injuries across diverse worker populations.

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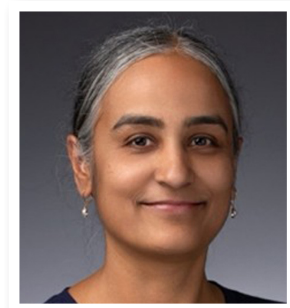

Priyadarshini Pennathur

Arunkumar Pennathur

Judy Jin, a Fellow of IISE, is the Director of Manufacturing Program of Integrative Systems and Design Division and a professor in the Department of Industrial and Operations Engineering at the University of Michigan. She is editor-in-chief of IISE Transactions. (link.iise.org/iisetransactions)

Ranjana Mehta is a professor and director of the NeuroErgonomics Lab in the Department of Industrial & Systems Engineering at the University of Wisconsin-Madison and editor-in-chief of IISE Transactions on Occupational Ergonomics and Human Factors. (link.iise.org/iisetransactions_ergonomics)