Guest Editorial
Privacy in Retrieval, Computing, and Learning

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THE increasing prevalence of massive datasets makes the outsourcing of storage and computation tasks to distributed servers a necessity. This raises a number of concerns regarding the security and integrity of stored information, the privacy of accessing desired information, the communication overhead of distributed systems, the latency, reliability, and complexity of distributed computing, and privacy in distributed training and learning systems. Recent breakthroughs from coding, communication, and information-theoretic perspectives have opened up exciting new research avenues for these topics. There are many theoretical and practical open problems. This Special Issue is dedicated to communication theory, coding theory, information theory, signal processing, and networking aspects of privacy in information retrieval, privacy in coded computing over distributed servers, and privacy in distributed learning.

The Special Issue starts with a guest editor-authored tutorial overview article [A1], in which Ulukus *et al.* review privacy in retrieval, computing, and learning, describe some of the commonly used techniques, and survey the state-of-the-art. The tutorial paper is then followed by 20 technical papers.

In [A2], Liu *et al.* propose a privacy-preserving distributed algorithm to maximize cache hit rates of devices in the edge networks. This is a challenging problem since content popularities are often dynamic, complicated, and unobservable. To approach this problem, authors formulate the maximization of cache hit rates on devices as distributed problems under the constraints of privacy preservation and then introduce a privacy-preserving federated learning method for popularity prediction.

In [A3], Sasidharan and Thomas consider a distributed learning scenario, in which the edge nodes are available intermittently and are connected via low-bandwidth links. The edge nodes communicate local gradients to helper nodes, and these helpers forward messages to the central node after possible aggregation. In this setting, the authors propose a new scheme for gradient aggregation in distributed machine learning. Their scheme makes use of a well-known class of pyramid codes, thus expanding the realm of application of locally repairable codes to distributed learning. This article also establishes a trade-off between communication costs at edge nodes and at helper nodes.

In [A4], Li and Song study the federated multi-armed bandit problem under a master–worker, a decentralized and a hybrid structure. Several algorithms are proposed, and the performance is analyzed in terms of the regret. The three measures, i.e., data privacy, communication cost, and regret, enjoy different behaviors under these algorithms, which reflects a complex trade-off relation among them.

In [A5], Schlegel *et al.* consider the problem of linear inference on local data over a mobile edge computing network. A novel coding scheme based on Shamir's secret sharing algorithm is proposed to provide information-theoretic privacy against a given number of colluding edge servers while minimizing the overall latency in the presence of straggling servers.

In [A6], Naim *et al.* consider a setting that involves a single server and multiple users, where each user holds a discrete value and belongs to one of the k distinct groups. The goal is to allow the server to find the aggregated values in each group, under communication and privacy constraints. A novel algorithm is proposed to accomplish this task, which distinguishes itself from existing approaches by taking an interactive approach.

In [A7], Zhu *et al.* explore how multiple users may jointly, privately, and efficiently retrieve a file from a secure distributed database when the storage is coded and the set of servers includes unresponsive and/or Byzantine servers. A solution is proposed based on a combination of interference alignment and Lagrange encoding.

In [A8], Yakimenka *et al.* studied a relaxed notion of single-server PIR, where, instead of perfect privacy and perfect retrievability, some information leakage and distortion are allowed in order to reduce the download cost. The optimal trade-off between rate, distortion, and leakage is characterized

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for large file sizes, and a construction based on linear programming is proposed for arbitrary file sizes.

In [A9], Obead *et al.* study a generalization of PIR, which allows a user to compute a linear combination of the messages that are stored in a coded fashion across distributed servers while keeping the combining coefficients private. The capacity is characterized for MDS coded storage.

In [A10], Budkuley *et al.* study the problem of commitment over a class of channels referred to as reverse elastic channels, which is a model of channel uncertainty. The authors establish a number of capacity theorems. They also present a conjecture on the commitment capacity of a symmetric channel instance.

In [A11], Li *et al.* develop a novel server cooperation strategy. In their model, the servers both cooperate and collude. The authors explain how their strategy can be put to use in the problems of secure distributed matrix multiplication (SDMM) and (linear) private information retrieval (PIR).

In [A12], Allaix *et al.* establish more general results for the problem of private information retrieval in quantum models. Achievable schemes are developed based on linear and MDS codes. The article also presents new converse bounds.

In [A13], Heidarzadeh *et al.* introduce the problem of private linear transformation (PLT) to generalize the problems of private information retrieval and private linear computation. Capacity results are established for two different special cases (referred to as JPLT-I and JPLT-II).

In [A14], Wan *et al.* present a novel framework for secure and distributed computation of linearly separable functions. Achievable schemes are proposed which can trade-off between local computational capabilities, common randomness, and the number of stragglers. In addition, converse results establishing the optimality of some of the schemes are also derived.

In [A15], Ye and El Rouayheb formulate and study the problem of intermittent private information retrieval, motivated by the need for privacy in location-based applications. The queries within this context involve correlated requests over time, and privacy requirements may only be necessary for some parts of requests. The authors develop a combination of obfuscation and PIR-based techniques for this problem while adapting them to the correlation structure between the requests.

In [A16], Shariatnasab *et al.* consider active deanonymization attacks within the context of bipartite networks and study the fundamental privacy limits. Specifically, attack algorithms are proposed by leveraging techniques from feedback communication with the goal of minimizing the number of queries needed for deanonymization. Theoretical analysis for stochastic models is presented together with simulation results.

In [A17], Hasircioglu *et al.* study the problem of secure distributed matrix multiplication and adapt bivariate polynomial codes for this scenario. These codes provide information-theoretic security guarantees and are shown to further speed up distributed matrix multiplication and reduce average computation time (compared to existing approaches in the literature), by exploiting partial work done by stragglers.

In [A18], Yan and Tuninetti address the problem of cache-aided robust, secure, demand-private scalar linear function retrieval in a multi-server setup. The authors use the key-superposition technique to simultaneously satisfy the constraints of content security against eavesdroppers, privacy of user demands against colluding users, and privacy of user demands against servers.

In [A19], Kurt *et al.* propose an algorithm which uses observed data sequence to detect network anomalies while maintaining data privacy and limiting the risk of false alarms. The emphasis of the article is on finding a model-free (data-driven) solution for anomaly detection since estimating the nominal model behavior is intractable due to large network size, and time-changing anomalous behavior.

In [A20], Song and Hayashi explore the connection between two important security primitives—symmetric private information retrieval and secret sharing, and establish a weak equivalence result between the two problems. The two primitives both have many applications, and the equivalence results found further connect them improving our understanding.

In [A21], Hong *et al.* consider a distributed computing framework for matrix multiplication where some of the workers are Byzantine, i.e., they send wrong computations to the master node. The article provides suitable solutions for identifying the Byzantine workers by proposing the use of locally testable codes together with a hierarchical group testing algorithm.

Appendix: Related Articles

[A1] S. Ulukus, S. Avestimehr, M. Gastpar, S. Jafar, R. Tandon, and C. Tian, "Private retrieval, computing, and learning: Recent progress and future challenges," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 3, Mar. 2022, doi: 10.1109/JSAC.2022.3142358.

[A2] S. Liu, C. Zheng, Y. Huang, and T. Q. S. Quek, "Distributed reinforcement learning for privacy-preserving dynamic edge caching," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 3, Mar. 2022, doi: 10.1109/JSAC.2022.3142348.

[A3] B. Sasidharan and A. Thomas, "Coded gradient aggregation: A tradeoff between communication costs at edge nodes and at helper nodes," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 3, Mar. 2022, doi: doi: 10.1109/JSAC.2022.3142356.

[A4] T. Li and L. Song, "Privacy-preserving communication-efficient federated multi-armed bandits," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 3, Mar. 2022, doi: 10.1109/JSAC.2022.3142374.

[A5] R. Schlegel, S. Kumar, E. Rosnes, and A. G. I. Amat, "Privacy-preserving coded mobile edge computing for low-latency distributed inference," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 3, Mar. 2022, doi: 10.1109/JSAC.2022.3142295.

[A6] C. Naim, R. G. L. D'Oliveira, and S. El Rouayheb, "Private multi-group aggregation," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 3, Mar. 2022, doi: 10.1109/JSAC.2022.3142357.

[A7] J. Zhu, Q. Yan, and X. Tang, "Multi-user blind symmetric private information retrieval from coded servers," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 3, Mar. 2022, doi: 10.1109/JSAC.2022.3142352.

[A8] Y. Yakimenka, H.-Y. Lin, E. Rosnes, and J. Kliewer, "Optimal rate-distortion-leakage tradeoff for single-server information retrieval," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 3, Mar. 2022, doi: 10.1109/JSAC.2022.3142296.

[A9] S. A. Obead, H.-Y. Lin, E. Rosnes, and J. Kliewer, "Private linear computation for noncolluding coded databases," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 3, Mar. 2022, doi: 10.1109/JSAC.2022.3142362.

[A10] A. Budkuley, P. Joshi, M. Mamindlapally, and A. K. Yadav, "On reverse elastic channels and the asymmetry of commitment capacity under channel with under channel elasticity," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 3, Mar. 2022, doi: 10.1109/JSAC.2022.3142304.

[A11] J. Li, O. Makkonen, C. Hollanti, and O. Gnilke, "Efficient recovery of a shared secret via cooperation: Applications to SDMM and PIR," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 3, Mar. 2022, doi: 10.1109/JSAC.2022.3142366.

[A12] M. Allaix, S. Song, L. Holzbaur, T. Pllaha, M. Hayashi, and C. Hollanti, "On the capacity of quantum private information retrieval from MDS-coded and colluding servers," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 3, Mar. 2022, doi: 10.1109/JSAC.2022.3142363.

[A13] A. Heidarzadeh, N. Esmati, and A. Sprintson, "Single-server private linear transformation: The joint privacy case," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 3, Mar. 2022, doi: 10.1109/JSAC.2022.3142293.

[A14] K. Wan, H. Sun, M. Ji, and G. Caire, "On secure distributed linearly separable computation," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 3, Mar. 2022, doi: 10.1109/JSAC.2022.3142373.

[A15] F. Ye and S. El Rouayheb, "Intermittent private information retrieval with application to location privacy," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 3, Mar. 2022, doi: 10.1109/JSAC.2022.3142301.

[A16] M. Shariatnasab, F. Shirani, and E. Erkip, "Fundamental privacy limits in bipartite networks under active attacks," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 3, Mar. 2022, doi: 10.1109/JSAC.2022.3142299.

[A17] B. Hasırcıoğlu, J. Gómez-Vilardebó, and D. Gündüz, "Bivariate polynomial codes for secure distributed matrix multiplication," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 3, Mar. 2022, doi: 10.1109/JSAC.2022.3142355.

[A18] Q. Yan and D. Tuninetti, "Robust, private and secure cache-aided scalar linear function retrieval from coded servers," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 3, Mar. 2022, doi: 10.1109/JSAC.2022.3142360.

[A19] M. N. Kurt, Y. Yılmaz, X. Wang, and P. J. Mosterman, "Online privacy-preserving data-driven network anomaly detection," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 3, Mar. 2022, doi: 10.1109/JSAC.2022.3142302.

[A20] S. Song and M. Hayashi, "Equivalence of non-perfect secret sharing and symmetric private information retrieval with general access structure," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 3, Mar. 2022, doi: 10.1109/JSAC.2022.3142375.

[A21] S. Hong, H. Yang, and J. Lee, "Hierarchical group testing for Byzantine attack identification in distributed matrix multiplication," *IEEE J. Sel. Areas Commun.*, vol. 40, no. 3, Mar. 2022, doi: 10.1109/JSAC.2022.3142364.

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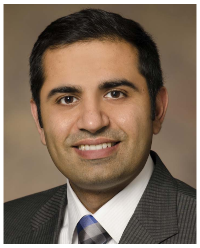

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