References

- [1] K. A, V. P. M. Shaaban, and W. C.L. Heterogeneous computing: Challenges and opportunities. In IEEE Computer, 1993.
- [2] S. Akoush, L. Carata, R. Sohan, and A. Hopper. Mrlazy: Lazy runtime label propagation for mapreduce. In Proceedings of the 6th USENIX Conference on Hot Topics in Cloud Computing, HotCloud'14, pages 17-17, Berkeley, CA, USA, 2014. USENIX Association. URL http://dl.acm.org/citation.cfm?id=2696535.2696552.
- [3] M. Armbrust, R. S. Xin, C. Lian, Y. Huai, D. Liu, J. K. Bradley, X. Meng, T. Kaftan, M. J. Franklin, A. Ghodsi, et al. Spark sql: Relational data processing in spark. In Proceedings of the 2015 ACM SIGMOD International Conference on Management of Data, pages 1383–1394. ACM, 2015.
- [4] S. Bajaj and R. Sion. Trusteddb: A trusted hardware based database with privacy and data confidentiality. In Proceedings of the 2011 ACM SIGMOD International Conference on Management of Data, SIGMOD '11, pages 205-216, New York, NY, USA, 2011. ACM. ISBN 978-1-4503-0661-4. doi: 10.1145/1989323.1989346. URL http://doi.acm.org/10.1145/1989323.1989346.
- [5] J. Bell and G. Kaiser. Phosphor: Illuminating dynamic data flow in commodity jvms. In Proceedings of the 2014 ACM International Conference on Object Oriented Programming Systems Languages & Applications, OOPSLA '14, pages 83-101, New York, NY, USA, 2014. ACM. ISBN 978-1-4503-2585-1. doi: 10.1145/2660193.2660212. URL http://doi.acm.org/10.1145/2660193.2660212
- [6] S. Brenner, C. Wulf, D. Goltzsche, N. Weichbrodt, M. Lorenz, C. Fetzer, P. R. Pietzuch, and R. Kapitza. Securekeeper: Confidential zookeeper using intel sgx. In *Middleware*, page 14, 2016.
- [7] C. B.W.L., W. C.L., and K. Hwang. A migrating-home protocol for implementing scope consistency model on a cluster of workstations. In PDPTA, 1999.
- [8] Z. Chothia, J. Liagouris, F. McSherry, and T. Roscoe. Explaining outputs in modern data analytics. Proceedings of the VLDB Endowment, 9(12):1137–1148, 2016.
- [9] H. Cui, J. Wu, C.-C. Tsai, and J. Yang. Stable deterministic multithreading through schedule memoization. In Proceedings of the Ninth Symposium on Operating Systems Design and Implementation (OSDI '10), Oct. 2010.
- [10] H. Cui, J. Wu, J. Gallagher, H. Guo, and J. Yang. Efficient deterministic multithreading through schedule relaxation. In Proceedings of the 23rd ACM Symposium on Operating Systems Principles (SOSP '11), pages 337–351, Oct. 2011.
- [11] H. Cui, J. Simsa, Y.-H. Lin, H. Li, B. Blum, X. Xu, J. Yang, G. A. Gibson, and R. E. Bryant. Parrot: a practical runtime for deterministic, stable, and reliable threads. In Proceedings of the 24th ACM Symposium on Operating Systems Principles (SOSP '13), Nov. 2013.
- [12] H. Cui, R. Gu, C. Liu, and J. Yang. Paxos made transparent. In Proceedings of the 25th ACM Symposium on Operating Systems Principles (SOSP '15), Oct. 2015.
- [13] A. Dave and M. Zaharia. Arthur: Rich post-facto debugging for production analytics applications.
- [14] J. Dean and S. Ghemawat. Mapreduce: simplified data processing on large clusters. In OSDI'04: Proceedings of the 6th conference on Symposium on Opearting Systems Design & Implementation, pages 10–10, 2004.
- [15] C. Dwork, F. McSherry, K. Nissim, and A. Smith. Calibrating noise to sensitivity in private data analysis. In Proceedings of the Third Conference on Theory of Cryptography, TCC'06, pages 265–284, Berlin, Heidelberg, 2006. Springer-Verlag. ISBN 3-540-32731-2, 978-3-540-32731-8. doi: 10.1007/11681878_14. URL http://dx.doi.org/10.1007/11681878_14.
- [16] T. ElGamal. A public key cryptosystem and a signature scheme based on discrete logarithms. IEEE transactions on information theory, 31(4):469–472, 1985.
- [17] W. Enck, P. Gilbert, B.-G. Chun, L. P. Cox, J. Jung, P. McDaniel, and A. N. Sheth. TaintDroid: an information-flow tracking system for realtime privacy monitoring on smartphones. In *Proceedings of the Ninth Symposium on Operating Systems Design and Implementation (OSDI '10)*, pages 1–6, 2010.
- [18] L. Feng, L. F.C.M., C. Heming, and W. Cho-Li. Confluence: Speeding up iterative distributed operations by key-dependency-aware partitioning. In *IEEE Transactions on Parallel and Distributed Systems (TPDS)*, 2017.
- [19] A. F. Gates, O. Natkovich, S. Chopra, P. Kamath, S. M. Narayanamurthy, C. Olston, B. Reed, S. Srinivasan, and U. Srivastava. Building a high-level dataflow system on top of map-reduce: The pig experience. Proc. VLDB Endow., 2(2):1414–1425, Aug. 2009. ISSN 2150-8097. doi: 10.14778/1687553.1687568. URL https://doi.org/10.14778/1687553.1687568.
- [20] C. Gentry, S. Halevi, and N. P. Smart. Homomorphic evaluation of the aes circuit. In Advances in Cryptology-CRYPTO 2012, pages 850–867. Springer, 2012.
- [21] C. Gentry et al. Fully homomorphic encryption using ideal lattices. In STOC, volume 9, pages 169–178, 2009.
- [22] M. A. Gulzar, M. Interlandi, S. Yoo, S. D. Tetali, T. Condie, T. Millstein, and M. Kim. Bigdebug: Debugging primitives for interactive big data processing in spark. In *Proceedings of the 38th International Conference on Software Engineering*, ICSE '16, pages 784-795, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-3900-1. doi: 10.1145/2884781.2884813. URL http://doi.acm.org/10.1145/2884781.2884813.
- [23] X. Hu, M. Yuan, J. Yao, Y. Deng, L. Chen, Q. Yang, H. Guan, and J. Zeng. Differential privacy in telco big data platform. Proceedings of the VLDB Endowment, 8(12):1692–1703, 2015.
- [24] R. Ikeda, H. Park, and J. Widom. Provenance for generalized map and reduce workflows. In CIDR 2011. Stanford InfoLab. URL http://ilpubs.stanford.edu:8090/985/.

- [25] Intel. Software guard extensions programming reference. https://software.intel.com/sites/default/files/329298-001.pdf.
- [26] M. Interlandi, K. Shah, S. D. Tetali, M. A. Gulzar, S. Yoo, M. Kim, T. Millstein, and T. Condie. Titian: Data provenance support in spark. Proc. VLDB Endow., 9(3):216-227, Nov. 2015. ISSN 2150-8097. doi: 10.14778/2850583.2850595. URL http://dx.doi.org/10.14778/2850583.2850595.
- [27] J. Jianyu, Z. Shixiong, A. Danish, W. Yuexuan, C. Heming, L. Feng, and G. Zhaoquan. Kakute: A precise, unified information flow analysis system for big-data security. In *Proceedings of the Annual Computer Security Applications Conference (ACSAC* '17), 2017.
- [28] H. K., J. H., C. E., W. C.L., and X. Z. Designing ssi clusters with hierarchical checkpointing and single i/o space. In IEEE Concurrency, 1999.
- [29] V. P. Kemerlis, G. Portokalidis, K. Jee, and A. D. Keromytis. Libdft: Practical dynamic data flow tracking for commodity systems. In Proceedings of the 8th ACM SIGPLAN/SIGOPS Conference on Virtual Execution Environments, VEE '12, pages 121-132, New York, NY, USA, 2012. ACM. ISBN 978-1-4503-1176-2. doi: 10.1145/2151024.2151042. URL http://doi.acm.org/10.1145/ 2151024.2151042.
- [30] L. King-Tin, S. Jinghao, H. Dominic, W. Cho-Li, L. Zhiquan, Z. Wangbin, and Y. Youliang. Rhymes: A shared virtual memory system for non-coherent tiled many-core architectures. In *ICPADS 2014*, 2014.
- [31] D. Logothetis, S. De, and K. Yocum. Scalable lineage capture for debugging disc analytics. In *Proceedings of the 4th annual Symposium on Cloud Computing*, page 17. ACM, 2013.
- [32] A. Machanavajjhala, J. Gehrke, D. Kifer, and M. Venkitasubramaniam. l-diversity: Privacy beyond k-anonymity. In Data Engineering, 2006. ICDE'06. Proceedings of the 22nd International Conference on, pages 24–24. IEEE, 2006.
- [33] F. McKeen, I. Alexandrovich, I. Anati, D. Caspi, S. Johnson, R. Leslie-Hurd, and C. Rozas. Intel® software guard extensions (intel® sgx) support for dynamic memory management inside an enclave. In *Proceedings of the Hardware and Architectural Support for Security and Privacy 2016*, page 10. ACM, 2016.
- [34] F. McSherry. Privacy integrated queries. In Proceedings of the 2009 ACM SIGMOD International Conference on Management of Data (SIGMOD). Association for Computing Machinery, Inc., June 2009. URL https://www.microsoft.com/en-us/research/ publication/privacy-integrated-queries/.
- [35] F. McSherry and K. Talwar. Mechanism design via differential privacy. In Proceedings of the 48th Annual IEEE Symposium on Foundations of Computer Science, FOCS '07, pages 94-103, Washington, DC, USA, 2007. IEEE Computer Society. ISBN 0-7695-3010-9. doi: 10.1109/FOCS.2007.41. URL http://dx.doi.org/10.1109/FOCS.2007.41.
- [36] M. M.J.M., W. C.L., and L. F.C.M. Jessica: Java-enabled single-system-image computing architecture. In Journal of Parallel and Distributed Computing, 2000.
- [37] P. Mohan, A. Thakurta, E. Shi, D. Song, and D. Culler. Gupt: Privacy preserving data analysis made easy. In Proceedings of the 2012 ACM SIGMOD International Conference on Management of Data, SIGMOD '12, pages 349-360, New York, NY, USA, 2012. ACM. ISBN 978-1-4503-1247-9. doi: 10.1145/2213836.2213876. URL http://doi.acm.org/10.1145/2213836.2213876.
- [38] J. Newsome and D. Song. Dynamic taint analysis for automatic detection, analysis, and signature generation of exploits on commodity software. 2005.
- [39] O. Ohrimenko, F. Schuster, C. Fournet, A. Mehta, S. Nowozin, K. Vaswani, and M. Costa. Oblivious multi-party machine learning on trusted processors. In 25th USENIX Security Symposium (USENIX Security 16), pages 619-636, Austin, TX, 2016. USENIX Association. ISBN 978-1-931971-32-4. URL https://www.usenix.org/conference/usenixsecurity16/technical-sessions/ presentation/ohrimenko.
- [40] C. Olston, B. Reed, U. Srivastava, R. Kumar, and A. Tomkins. Pig latin: a not-so-foreign language for data processing. In Proceedings of the 2008 ACM SIGMOD international conference on Management of data, pages 1099–1110. ACM, 2008.
- [41] P. Paillier et al. Public-key cryptosystems based on composite degree residuosity classes. In Eurocrypt, volume 99, pages 223–238. Springer, 1999.
- [42] A. Papadimitriou, R. Bhagwan, N. Chandran, R. Ramjee, A. Haeberlen, H. Singh, A. Modi, and S. Badrinarayanan. Big data analytics over encrypted datasets with seabed. In OSDI, pages 587–602, 2016.
- [43] V. Pappas, V. P. Kemerlis, A. Zavou, M. Polychronakis, and A. D. Keromytis. Cloudfence: Data flow tracking as a cloud service. In Proceedings of the 16th International Symposium on Research in Attacks, Intrusions, and Defenses Volume 8145, RAID 2013, pages 411–431, New York, NY, USA, 2013. Springer-Verlag New York, Inc. ISBN 978-3-642-41283-7. doi: 10.1007/978-3-642-41284-4_21. URL http://dx.doi.org/10.1007/978-3-642-41284-4_21.
- $[44] \ \ pigmix. \ \ \texttt{https://cwiki.apache.org/confluence/display/PIG/PigMix}.$
- [45] R. A. Popa, C. Redfield, N. Zeldovich, and H. Balakrishnan. Cryptdb: protecting confidentiality with encrypted query processing. In Proceedings of the Twenty-Third ACM Symposium on Operating Systems Principles, pages 85–100. ACM, 2011.
- [46] I. Roy, S. T. V. Setty, A. Kilzer, V. Shmatikov, and E. Witchel. Airavat: Security and privacy for mapreduce. In Proceedings of the 7th USENIX Conference on Networked Systems Design and Implementation, NSDI'10, pages 20-20, Berkeley, CA, USA, 2010. USENIX Association. URL http://dl.acm.org/citation.cfm?id=1855711.1855731.
- [47] F. Schuster, M. Costa, C. Fournet, C. Gkantsidis, M. Peinado, G. Mainar-Ruiz, and M. Russinovich. Vc3: Trustworthy data analytics in the cloud using sgx. In Security and Privacy (SP), 2015 IEEE Symposium on, pages 38–54. IEEE, 2015.
- [48] F. Shaon, M. Kantarcioglu, Z. Lin, and L. Khan. Sgx-bigmatrix: A practical encrypted data analytic framework with trusted processors. In Proceedings of the 17th ACM conference on Computer and communications security (CCS '10), 2017.

- [49] D. Sheng and W. Cho-Li. Error-tolerant resource allocation and payment minimization for cloud system. In IEEE Transactions on Parallel and Distributed Systems (TPDS), 2013.
- [50] D. Sheng, R. Yves, V. Frederic, K. Derrick, W. Cho-Li, and C. Franck. Optimization of cloud task processing with checkpoint-restart mechanism. In SC '13, 2013.
- [51] D. Sheng, K. Derrick, and W. Cho-Li. Optimization of composite cloud service processing with virtual machines. In IEEE Transactions on Computers, 2014.
- [52] A. Smith. Privacy-preserving statistical estimation with optimal convergence rates. In Proceedings of the Forty-third Annual ACM Symposium on Theory of Computing, STOC '11, pages 813-822, New York, NY, USA, 2011. ACM. ISBN 978-1-4503-0691-1. doi: 10.1145/1993636.1993743. URL http://doi.acm.org/10.1145/1993636.1993743.
- [53] Spark example. https://spark.apache.org/examples.html.
- [54] J. J. Stephen, S. Savvides, R. Seidel, and P. Eugster. Practical confidentiality preserving big data analysis. In 6th USENIX Workshop on Hot Topics in Cloud Computing (HotCloud 14), Philadelphia, PA, 2014. USENIX Association. URL https://www.usenix.org/conference/hotcloud14/workshop-program/presentation/stephen.
- [55] L. Sweeney. k-anonymity: A model for protecting privacy. International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems, 10(05):557-570, 2002.
- [56] Y. Tang, P. Ames, S. Bhamidipati, A. Bijlani, R. Geambasu, and N. Sarda. CleanOS: limiting mobile data exposure with idle eviction. In Proceedings of the Tenth Symposium on Operating Systems Design and Implementation (OSDI '12), pages 77-91, 2012.
- [57] S. D. Tetali, M. Lesani, R. Majumdar, and T. Millstein. Mrcrypt: Static analysis for secure cloud computations. In Proceedings of the 2013 ACM SIGPLAN International Conference on Object Oriented Programming Systems Languages & Applications, OOPSLA '13, pages 271-286, New York, NY, USA, 2013. ACM. ISBN 978-1-4503-2374-1. doi: 10.1145/2509136.2509554. URL http://doi.acm.org/10.1145/2509136.2509554.
- [58] H. Tian, Y. Zhang, C. Xing, and S. Yan. Sgxkernel: A library operating system optimized for intel sgx. In Proceedings of the Computing Frontiers Conference, pages 35–44. ACM, 2017.
- [59] S. Tu, M. F. Kaashoek, S. Madden, and N. Zeldovich. Processing analytical queries over encrypted data. In Proceedings of the VLDB Endowment, volume 6, pages 289–300. VLDB Endowment, 2013.
- [60] Z. W, W. Cho-Li, , and L. F.C.M. Jessica2: A distributed java virtual machine with transparent thread migration support. In IEEE Fourth International Conference on Cluster Computing (Cluster2002), 2002.
- [61] C. Wang, J. Yang, N. Yi, and H. Cui. Tripod: An efficient, highly-available cluster management system. In Proceedings of the 7th ACM SIGOPS Asia-Pacific Workshop on Systems, APSys '16, 2016.
- [62] J. Yang, H. Cui, J. Wu, Y. Tang, and G. Hu. Determinism is not enough: Making parallel programs reliable with stable multithreading. *Communications of the ACM*, 2014.
- [63] Y. Yu, M. Isard, D. Fetterly, M. Budiu, Ú. Erlingsson, P. K. Gunda, and J. Currey. Dryadlinq: A system for general-purpose distributed data-parallel computing using a high-level language.
- [64] M. Zaharia, M. Chowdhury, T. Das, A. Dave, J. Ma, M. McCauley, M. J. Franklin, S. Shenker, and I. Stoica. Resilient distributed datasets: A fault-tolerant abstraction for in-memory cluster computing. In Proceedings of the 9th USENIX conference on Networked Systems Design and Implementation, pages 2-2. USENIX Association, 2012.
- [65] K. Zhang, X. Zhou, Y. Chen, X. Wang, and Y. Ruan. Sedic: privacy-aware data intensive computing on hybrid clouds. In Proceedings of the 18th ACM conference on Computer and communications security, pages 515–526. ACM, 2011.
- [66] W. Zheng, A. Dave, J. G. Beekman, R. A. Popa, J. E. Gonzalez, and I. Stoica. Opaque: An oblivious and encrypted distributed analytics platform. In NSDI, pages 283–298, 2017.
- [67] L. Zhiquan, L. King-Tin, W. Cho-Li, , and S. Jinshu. Powerock: Power modeling and flexible dynamic power management for many-core architectures. In IEEE Systems Journal, 2016.
- [68] W. Zhou, S. Mapara, Y. Ren, Y. Li, A. Haeberlen, Z. Ives, B. T. Loo, and M. Sherr. Distributed time-aware provenance. In Proceedings of the VLDB Endowment, volume 6, pages 49–60. VLDB Endowment, 2012.