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## References

- Pankaj Agarwal, Sariel Har, Peled Kasturi, and R Varadarajan. Geometric approximation via coresets. *Combinatorial* and Computational Geometry, 52, 11 2004.
- [2] Samet Akcay, Amir Atapour-Abarghouei, and Toby P Breckon. Ganomaly: Semi-supervised anomaly detection via adversarial training. In *Asian Conference on Computer Vision*, pages 622–637. Springer, 2018. 1, 2, 5, 8, 4
- [3] Jerone Andrews, Thomas Tanay, Edward Morton, and Lewis Griffin. Transfer representation-learning for anomaly detection. 07 2016. 4
- [4] Liron Bergman, Niv Cohen, and Yedid Hoshen. Deep nearest neighbor anomaly detection. *CoRR*, abs/2002.10445, 2020. 1, 2, 3
- [5] Paul Bergmann, Michael Fauser, David Sattlegger, and Carsten Steger. Mvtec ad – a comprehensive real-world dataset for unsupervised anomaly detection. In *Proceedings* of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), June 2019. 1, 2, 5, 6, 7, 4
- [6] Paul Bergmann, Michael Fauser, David Sattlegger, and Carsten Steger. Uninformed students: Student-teacher anomaly detection with discriminative latent embeddings. In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), June 2020. 2, 5, 7,
- [7] Paul Bergmann, Sindy Löwe, Michael Fauser, David Sattlegger, and Carsten Steger. Improving unsupervised defect segmentation by applying structural similarity to autoencoders. Proceedings of the 14th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications, 2019.
- [8] Wieland Brendel and Matthias Bethge. Approximating CNNs with bag-of-local-features models works surprisingly well on imagenet. In *International Conference on Learning Representations*, 2019. 2
- [9] Kenneth L. Clarkson. Coresets, sparse greedy approximation, and the frank-wolfe algorithm. ACM Trans. Algorithms, 6(4), Sept. 2010.
- [10] Niv Cohen and Yedid Hoshen. Sub-image anomaly detection with deep pyramid correspondences. CoRR, abs/2005.02357, 2020. 1, 2, 3, 4, 5, 6, 7, 8
- [11] Sanjoy Dasgupta and Anupam Gupta. An elementary proof of a theorem of johnson and lindenstrauss. *Random Struc*tures & Algorithms, 22(1):60–65, 2003. 4
- [12] Diana Davletshina, Valentyn Melnychuk, Viet Tran, Hitansh Singla, Max Berrendorf, Evgeniy Faerman, Michael Fromm, and Matthias Schubert. Unsupervised anomaly detection for x-ray images, 2020. 1

- [13] Lucas Deecke, Robert Vandermeulen, Lukas Ruff, Stephan Mandt, and Marius Kloft. Image anomaly detection with generative adversarial networks. In Michele Berlingerio, Francesco Bonchi, Thomas Gärtner, Neil Hurley, and Georgiana Ifrim, editors, Machine Learning and Knowledge Discovery in Databases, pages 3–17, Cham, 2019. Springer International Publishing. 2
- [14] Thomas Defard, Aleksandr Setkov, Angelique Loesch, and Romaric Audigier. Padim: A patch distribution modeling framework for anomaly detection and localization. In Alberto Del Bimbo, Rita Cucchiara, Stan Sclaroff, Giovanni Maria Farinella, Tao Mei, Marco Bertini, Hugo Jair Escalante, and Roberto Vezzani, editors, Pattern Recognition. ICPR International Workshops and Challenges, pages 475–489, Cham, 2021. Springer International Publishing. 2, 3, 5, 6, 7, 8, 1, 4
- [15] David Dehaene, Oriel Frigo, Sébastien Combrexelle, and Pierre Eline. Iterative energy-based projection on a normal data manifold for anomaly localization. In *International Conference on Learning Representations*, 2020. 6, 4
- [16] J. Deng, W. Dong, R. Socher, L. Li, Kai Li, and Li Fei-Fei. Imagenet: A large-scale hierarchical image database. In 2009 IEEE Conference on Computer Vision and Pattern Recognition, pages 248–255, 2009.
- [17] Laurent Dinh, Jascha Sohl-Dickstein, and Samy Bengio. Density estimation using real NVP. In 5th International Conference on Learning Representations, ICLR 2017, Toulon, France, April 24-26, 2017, Conference Track Proceedings. OpenReview.net, 2017. 2
- [18] Eleazar Eskin, Andrew Arnold, Michael Prerau, Leonid Portnoy, and Sal Stolfo. A Geometric Framework for Unsupervised Anomaly Detection, pages 77–101. Springer US, Boston, MA, 2002.
- [19] Dan Feldman, Matthew Faulkner, and Andreas Krause. Scalable training of mixture models via coresets. In J. Shawe-Taylor, R. Zemel, P. Bartlett, F. Pereira, and K. Q. Weinberger, editors, Advances in Neural Information Processing Systems, volume 24, pages 2142–2150. Curran Associates, Inc., 2011. 2
- [20] Izhak Golan and Ran El-Yaniv. Deep anomaly detection using geometric transformations. In S. Bengio, H. Wallach, H. Larochelle, K. Grauman, N. Cesa-Bianchi, and R. Garnett, editors, Advances in Neural Information Processing Systems, volume 31, pages 9758–9769. Curran Associates, Inc., 2018. 2, 4
- [21] Dong Gong, Lingqiao Liu, Vuong Le, Budhaditya Saha, Moussa Reda Mansour, Svetha Venkatesh, and Anton van den Hengel. Memorizing normality to detect anomaly: Memory-augmented deep autoencoder for unsupervised anomaly detection. In Proceedings of the IEEE/CVF International Conference on Computer Vision (ICCV), October 2019. 2
- [22] Sariel Har-Peled and Akash Kushal. Smaller coresets for k-median and k-means clustering. *Discrete and Computational Geometry*, 37:3–19, 12 2007.
- [23] Kaiming He, Xiangyu Zhang, Shaoqing Ren, and Jian Sun. Deep residual learning for image recognition. In *Proceed-*



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## References

- [1] Pankaj Agarwal, Sariel Har, Peled Kasturi, and R Varadarajan. Geometric approximation via coresets. *Combinatorial* and Computational Geometry, 52, 11 2004. 2, 4
- [2] Samet Akcay, Amir Atapour-Abarghouei, and Toby P Breckon. Ganomaly: Semi-supervised anomaly detection via adversarial training. In *Asian Conference on Computer Vision*, pages 622–637. Springer, 2018. 1, 2, 5, 8, 4
- [3] Jerone Andrews, Thomas Tanay, Edward Morton, and Lewis Griffin. Transfer representation-learning for anomaly detection. 07 2016. 4
- [4] Liron Bergman, Niv Cohen, and Yedid Hoshen. Deep nearest neighbor anomaly detection. *CoRR*, abs/2002.10445, 2020. 1, 2, 3
- [5] Paul Bergmann, Michael Fauser, David Sattlegger, and Carsten Steger. Mytec ad a comprehensive real-world dataset for unsupervised anomaly detection. In *Proceedings* of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), June 2019. 1, 2, 5, 6, 7, 4
- [6] Paul Bergmann, Michael Fauser, David Sattlegger, and Carsten Steger. Uninformed students: Student-teacher anomaly detection with discriminative latent embeddings. In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), June 2020. 2, 5, 7, 4
- [7] Paul Bergmann, Sindy Löwe, Michael Fauser, David Sattlegger, and Carsten Steger. Improving unsupervised defect segmentation by applying structural similarity to autoencoders. Proceedings of the 14th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications, 2019.
- [8] Wieland Brendel and Matthias Bethge. Approximating CNNs with bag-of-local-features models works surprisingly well on imagenet. In *International Conference on Learning Representations*, 2019. 2
- [9] Kenneth L. Clarkson. Coresets, sparse greedy approximation, and the frank-wolfe algorithm. ACM Trans. Algorithms, 6(4), Sept. 2010. 2
- [10] Niv Cohen and Yedid Hoshen. Sub-image anomaly detection with deep pyramid correspondences. CoRR, abs/2005.02357, 2020. 1, 2, 3, 4, 5, 6, 7, 8
- [11] Sanjoy Dasgupta and Anupam Gupta. An elementary proof of a theorem of johnson and lindenstrauss. *Random Structures & Algorithms*, 22(1):60–65, 2003. 4
- [12] Diana Davletshina, Valentyn Melnychuk, Viet Tran, Hitansh Singla, Max Berrendorf, Evgeniy Faerman, Michael Fromm, and Matthias Schubert. Unsupervised anomaly detection for x-ray images, 2020. 1

- [13] Lucas Deecke, Robert Vandermeulen, Lukas Ruff, Stephan Mandt, and Marius Kloft. Image anomaly detection with generative adversarial networks. In Michele Berlingerio, Francesco Bonchi, Thomas Gärtner, Neil Hurley, and Georgiana Ifrim, editors, *Machine Learning and Knowledge Dis*covery in Databases, pages 3–17, Cham, 2019. Springer International Publishing. 2
- [14] Thomas Defard, Aleksandr Setkov, Angelique Loesch, and Romaric Audigier. Padim: A patch distribution modeling framework for anomaly detection and localization. In Alberto Del Bimbo, Rita Cucchiara, Stan Sclaroff, Giovanni Maria Farinella, Tao Mei, Marco Bertini, Hugo Jair Escalante, and Roberto Vezzani, editors, *Pattern Recogni*tion. ICPR International Workshops and Challenges, pages 475–489, Cham, 2021. Springer International Publishing. 2, 3, 5, 6, 7, 8, 1, 4
- [15] David Dehaene, Oriel Frigo, Sébastien Combrexelle, and Pierre Eline. Iterative energy-based projection on a normal data manifold for anomaly localization. In *International Conference on Learning Representations*, 2020. 6, 4
- [16] J. Deng, W. Dong, R. Socher, L. Li, Kai Li, and Li Fei-Fei. Imagenet: A large-scale hierarchical image database. In 2009 IEEE Conference on Computer Vision and Pattern Recognition, pages 248–255, 2009.
- [17] Laurent Dinh, Jascha Sohl-Dickstein, and Samy Bengio. Density estimation using real NVP. In 5th International Conference on Learning Representations, ICLR 2017, Toulon, France, April 24-26, 2017, Conference Track Proceedings. OpenReview.net, 2017. 2
- [18] Eleazar Eskin, Andrew Arnold, Michael Prerau, Leonid Portnoy, and Sal Stolfo. A Geometric Framework for Unsupervised Anomaly Detection, pages 77–101. Springer US, Boston, MA, 2002.
- [19] Dan Feldman, Matthew Faulkner, and Andreas Krause. Scalable training of mixture models via coresets. In J. Shawe-Taylor, R. Zemel, P. Bartlett, F. Pereira, and K. Q. Weinberger, editors, *Advances in Neural Information Processing Systems*, volume 24, pages 2142–2150. Curran Associates, Inc., 2011. 2
- [20] Izhak Golan and Ran El-Yaniv. Deep anomaly detection using geometric transformations. In S. Bengio, H. Wallach, H. Larochelle, K. Grauman, N. Cesa-Bianchi, and R. Garnett, editors, *Advances in Neural Information Processing Systems*, volume 31, pages 9758–9769. Curran Associates, Inc., 2018. 2, 4
- [21] Dong Gong, Lingqiao Liu, Vuong Le, Budhaditya Saha, Moussa Reda Mansour, Svetha Venkatesh, and Anton van den Hengel. Memorizing normality to detect anomaly: Memory-augmented deep autoencoder for unsupervised anomaly detection. In *Proceedings of the IEEE/CVF Inter*national Conference on Computer Vision (ICCV), October 2019. 2
- [22] Sariel Har-Peled and Akash Kushal. Smaller coresets for k-median and k-means clustering. *Discrete and Computational Geometry*, 37:3–19, 12 2007.
- [23] Kaiming He, Xiangyu Zhang, Shaoqing Ren, and Jian Sun. Deep residual learning for image recognition. In *Proceed*-

