



Universiteit
Leiden
The Netherlands

Advancing learned algorithms for 2D X-ray computed tomography

Kiss, M.B.

Citation

Kiss, M. B. (2025, November 7). *Advancing learned algorithms for 2D X-ray computed tomography*. Retrieved from <https://hdl.handle.net/1887/4282439>

Version: Publisher's Version

License: [Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden](#)

Downloaded from: <https://hdl.handle.net/1887/4282439>

Note: To cite this publication please use the final published version (if applicable).

Bibliography

- [1] W. van Aarle, W. J. Palenstijn, J. Cant, E. Janssens, F. Bleichrodt, A. Dabravolski, J. D. Beenhouwer, K. J. Batenburg, and J. Sijbers. “Fast and flexible X-ray tomography using the ASTRA toolbox”. *Opt. Express* 24.22 (Oct. 2016), pp. 25129–25147 (cit. on pp. 99, 110, 112).
- [2] J. Adler, H. Kohr, and O. Öktem. *ODL 0.6.0*. Version v0.6.0. Apr. 2017 (cit. on p. 110).
- [3] J. Adler and O. Öktem. “Learned primal-dual reconstruction”. *IEEE Transactions on Medical Imaging* 37.6 (2018), pp. 1322–1332 (cit. on p. 113).
- [4] J. Adler and O. Öktem. “Solving ill-posed inverse problems using iterative deep neural networks”. *Inverse Problems* 33.12 (2017), p. 124007 (cit. on pp. 102, 113).
- [5] J. Als-Nielsen and D. McMorrow. *Elements of modern X-ray physics*. Hoboken, NJ: John Wiley & Sons, 2011 (cit. on pp. 40, 69).
- [6] J. Alzubi, A. Nayyar, and A. Kumar. “Machine learning from theory to algorithms: an overview”. In: *Journal of physics: conference series*. Vol. 1142. IOP Publishing. 2018, p. 012012 (cit. on p. 13).
- [7] O. Amir, D. Braunstein, and A. Altman. “Dose optimization tool”. In: *Medical Imaging 2003: Visualization, Image-Guided Procedures, and Display*. Vol. 5029. SPIE. 2003, pp. 815–821 (cit. on p. 84).
- [8] Amsterdam museum. *KA 18660 - Phallus Beurs*. 1500 - 1600 (cit. on p. 47).
- [9] M. Andonova. “Ancient basketry on the inside: X-ray computed microtomography for the non-destructive assessment of small archaeological monocotyledonous fragments: examples from Southeast Europe”. *Heritage Science* 9 (Dec. 2021) (cit. on p. 38).
- [10] S. G. Armato III, G. McLennan, L. Bidaut, M. F. McNitt-Gray, C. R. Meyer, A. P. Reeves, B. Zhao, D. R. Aberle, C. I. Henschke, E. A. Hoffman, et al. “The lung image database consortium (LIDC) and image database resource initiative (IDRI): a completed reference database of lung nodules on CT scans”. *Medical physics* 38.2 (2011), pp. 915–931 (cit. on p. 104).
- [11] S. Arridge, P. Maass, O. Öktem, and C.-B. Schönlieb. “Solving inverse problems using data-driven models”. *Acta Numerica* 28 (2019), pp. 1–174 (cit. on pp. 17, 102, 105, 106).
- [12] A. Barbu. “Training an active random field for real-time image denoising”. *IEEE Transactions on Image Processing* 18.11 (2009), pp. 2451–2462 (cit. on p. 106).

- [13] S. Barutcu, S. Aslan, A. K. Katsaggelos, and D. Gürsoy. “Limited-angle computed tomography with deep image and physics priors”. *Scientific Reports* 11.1 (2021), p. 17740 (cit. on p. 109).
- [14] A. Beck and M. Teboulle. “A fast iterative shrinkage-thresholding algorithm for linear inverse problems”. *SIAM Journal on Imaging Sciences* 2.1 (2009), pp. 183–202 (cit. on pp. 106, 107).
- [15] M. Beister, D. Kolditz, and W. A. Kalender. “Iterative reconstruction methods in X-ray CT”. *Physica Medica* 28.2 (2012), pp. 94–108 (cit. on p. 113).
- [16] M. Benning and M. Burger. “Modern regularization methods for inverse problems”. *Acta Numerica* 27 (2018), pp. 1–111 (cit. on p. 107).
- [17] T. M. Benson and B. K. De Man. “Synthetic CT noise emulation in the raw data domain”. In: *IEEE Nuclear Science Symposium & Medical Imaging Conference*. IEEE. 2010, pp. 3169–3171 (cit. on p. 84).
- [18] A. Biguri, M. Dosanjh, S. Hancock, and M. Soleimani. “TIGRE: a MATLAB-GPU toolbox for CBCT image reconstruction”. *Biomedical Physics & Engineering Express* 2.5 (2016), p. 055010 (cit. on p. 110).
- [19] A. Biguri, R. Lindroos, R. Bryll, H. Towsyfyan, H. Deyhle, I. El khalil Harrane, R. Boardman, M. Mavrogordato, M. Dosanjh, S. Hancock, et al. “Arbitrarily large tomography with iterative algorithms on multiple GPUs using the TIGRE toolbox”. *Journal of Parallel and Distributed Computing* 146 (2020), pp. 52–63 (cit. on p. 110).
- [20] A. Biguri and S. Mukherjee. “Advancing the frontiers of deep learning for low-dose 3D cone-beam computed tomography (CT) reconstruction”. In: *2024 IEEE International Conference on Acoustics, Speech, and Signal Processing Workshops (ICASSPW)*. IEEE. 2024, pp. 81–82 (cit. on pp. 85, 103).
- [21] F. E. Boas, D. Fleischmann, et al. “CT artifacts: causes and reduction techniques”. *Imaging Med* 4.2 (2012), pp. 229–240 (cit. on p. 41).
- [22] J. M. Boone and J. A. Seibert. “An accurate method for computer-generating tungsten anode x-ray spectra from 30 to 140 kV”. *Medical Physics* 24.11 (1997), pp. 1661–1670 (cit. on pp. 12, 34, 43, 70).
- [23] F. G. Bossema, S. B. Coban, A. Kostenko, P. van Duin, J. Dorscheid, I. Garachon, E. Hermens, R. van Liere, and K. J. Batenburg. “Integrating expert feedback on the spot in a time-efficient explorative CT scanning workflow for cultural heritage objects”. *Journal of Cultural Heritage* 49 (2021), pp. 38–47 (cit. on pp. 7, 38).
- [24] F. G. Bossema, M. Domínguez-Delmás, W. J. Palenstijn, A. Kostenko, J. Dorscheid, S. B. Coban, E. Hermens, and K. J. Batenburg. “A novel method for dendrochronology of large historical wooden objects using line trajectory X-ray tomography”. *Scientific Reports* 11.1 (2021), p. 11024 (cit. on p. 38).

- [25] F. G. Bossema, P. J. van Laar, K. Meechan, D. O’Flynn, J. Dyer, T. van Leeuwen, S. Meijer, E. Hermens, and K. J. Batenburg. “Inside out: Fusing 3D imaging modalities for the internal and external investigation of multi-material museum objects”. *Digital Applications in Archaeology and Cultural Heritage* 31 (2023), e00296 (cit. on p. 132).
- [26] F. G. Bossema, W. J. Palenstijn, A. Heginbotham, M. Corona, T. van Leeuwen, R. van Liere, J. Dorscheid, D. O’Flynn, J. Dyer, E. Hermens, et al. “Enabling 3D CT-scanning of cultural heritage objects using only in-house 2D X-ray equipment in museums”. *Nature Communications* 15.1 (2024), p. 3939 (cit. on p. 132).
- [27] S. Boyd, N. Parikh, E. Chu, B. Peleato, J. Eckstein, et al. “Distributed optimization and statistical learning via the alternating direction method of multipliers”. *Foundations and Trends® in Machine learning* 3.1 (2011), pp. 1–122 (cit. on p. 107).
- [28] R. N. Bracewell and A. Riddle. “Inversion of fan-beam scans in radio astronomy”. *Astrophysical Journal*, vol. 150, p. 427 150 (1967), p. 427 (cit. on p. 4).
- [29] S. L. Brady, A. T. Trout, E. Somasundaram, C. G. Anton, Y. Li, and J. R. Dillman. “Improving image quality and reducing radiation dose for pediatric CT by using deep learning reconstruction”. *Radiology* 298.1 (2021), pp. 180–188 (cit. on p. 102).
- [30] A. Breger, A. Biguri, M. S. Landman, I. Selby, N. Amberg, E. Brunner, J. Gröhl, S. Hatamikia, C. Karner, L. Ning, et al. “A study of why we need to reassess full reference image quality assessment with medical images”. *arXiv preprint arXiv:2405.19097* (2024) (cit. on p. 90).
- [31] A. Breger, C. Karner, I. Selby, J. Gröhl, S. Dittmer, E. Lilley, J. Babar, J. Beckford, T. J. Sadler, S. Shahipasand, et al. “A study on the adequacy of common IQA measures for medical images”. *arXiv preprint arXiv:2405.19224* (2024) (cit. on p. 90).
- [32] D. J. Brenner and E. J. Hall. “Computed tomography—an increasing source of radiation exposure”. *New England journal of medicine* 357.22 (2007), pp. 2277–2284 (cit. on p. 81).
- [33] T. M. Buzug. *Computed tomography*. Springer, 2011 (cit. on p. 74).
- [34] F. Casali. “Chapter 2 X-ray and neutron digital radiography and computed tomography for cultural heritage”. In: ed. by D. Bradley and D. Creagh. Vol. 1. *Physical Techniques in the Study of Art, Archaeology and Cultural Heritage*. Elsevier, 2006, pp. 41–123 (cit. on p. 38).
- [35] E. Van de Casteele, D. Van Dyck, J. Sijbers, and E. Raman. “An energy-based beam hardening model in tomography”. *Physics in Medicine & Biology* 47.23 (2002), p. 4181 (cit. on pp. 11, 40, 69, 110, 118).

- [36] M. Cellina, M. Cè, G. Irmici, V. Ascenti, E. Caloro, L. Bianchi, G. Pellegrino, N. D’Amico, S. Papa, and G. Carrafiello. “Artificial intelligence in emergency radiology: where are we going?” *Diagnostics* 12.12 (2022), p. 3223 (cit. on p. 14).
- [37] A. Chambolle and T. Pock. “A first-order primal-dual algorithm for convex problems with applications to imaging”. *Journal of Mathematical Imaging and Vision* 40 (2011), pp. 120–145 (cit. on p. 113).
- [38] G. Chen, Z. Zhang, S. Xu, S. Jiang, X. Liu, P. Tang, S. Li, and X. Xiang. “An optimized filter design approach for enhancing imaging quality in industrial linear accelerator”. *Journal of X-Ray Science and Technology* Preprint (2024), pp. 1–14 (cit. on p. 132).
- [39] G. Chen and D. Needell. “Compressed sensing and dictionary learning”. *Finite Frame Theory: A Complete Introduction to Overcompleteness* 73 (2016), p. 201 (cit. on p. 107).
- [40] H. Chen, Y. Zhang, M. K. Kalra, F. Lin, Y. Chen, P. Liao, J. Zhou, and G. Wang. “Low-dose CT with a residual encoder-decoder convolutional neural network”. *IEEE Transactions on Medical Imaging* 36.12 (2017), pp. 2524–2535 (cit. on p. 102).
- [41] H. Chung, J. Kim, M. T. Mccann, M. L. Klasky, and J. C. Ye. “Diffusion Posterior Sampling for General Noisy Inverse Problems”. In: *The Eleventh International Conference on Learning Representations, ICLR 2023*. The International Conference on Learning Representations. 2023 (cit. on p. 133).
- [42] H. Chung, B. Sim, D. Ryu, and J. C. Ye. “Improving diffusion models for inverse problems using manifold constraints”. *Advances in Neural Information Processing Systems* 35 (2022), pp. 25683–25696 (cit. on p. 133).
- [43] S. B. Coban, F. Lucka, W. J. Palenstijn, D. Van Loo, and K. J. Batenburg. “Explorative imaging and its implementation at the FleX-ray Laboratory”. *Journal of Imaging* 6.4 (2020), p. 18 (cit. on pp. 25, 43, 49, 64).
- [44] C. B. daveynin. *GE LightSpeed CT scanner at Open House, Monroeville, Pennsylvania*. URL: <https://www.flickr.com/photos/daveynin/7417096292/> (visited on Nov. 26, 2024) (cit. on p. 2).
- [45] B. De Man, S. Basu, N. Chandra, B. Dunham, P. Edic, M. Iatrou, S. McOlash, P. Sainath, C. Shaughnessy, B. Tower, et al. “CatSim: a new computer assisted tomography simulation environment”. In: *Medical Imaging 2007: Physics of Medical Imaging*. Vol. 6510. SPIE. 2007, pp. 856–863 (cit. on p. 85).
- [46] J. Deng, W. Dong, R. Socher, L.-J. Li, K. Li, and L. Fei-Fei. “ImageNet: A large-scale hierarchical image database”. In: *2009 IEEE Conference on Computer Vision and Pattern Recognition*. IEEE. 2009, pp. 248–255 (cit. on pp. 15, 62, 101, 133).

- [47] H. Der Sarkissian, F. Lucka, M. van Eijnatten, G. Colacicco, S. Coban, and K. J. Batenburg. “A cone-beam X-ray computed tomography data collection designed for machine learning”. *Scientific Data* 6 (Oct. 2019), p. 215 (cit. on pp. 62, 103).
- [48] A. G. Dimakis, A. Bora, D. Van Veen, A. Jalal, S. Vishwanath, and E. Price. “Deep generative models and inverse problems”. *Mathematical Aspects of Deep Learning* (2022), pp. 400–421 (cit. on p. 107).
- [49] M. Domínguez-Delmás, F. Bossema, B. Van der Mark, A. Kostenko, S. Coban, S. Van Daalen, P. Van Duin, and K. Batenburg. “Dating and provenancing the Woman with lantern sculpture – A contribution towards attribution of Netherlandish art”. *Journal of Cultural Heritage* 50 (2021), pp. 179–187 (cit. on p. 38).
- [50] J. Dorscheid, F. G. Bossema, P. van Duin, S. B. Coban, R. van Liere, K. J. Batenburg, and G. P. Di Stefano. “Looking under the skin: multi-scale CT scanning of a peculiarly constructed cornett in the Rijksmuseum”. *Heritage Science* 10.1 (2022), p. 161 (cit. on p. 38).
- [51] A. Ebner and M. Haltmeier. “Plug-and-play image reconstruction is a convergent regularization method”. *IEEE Transactions on Image Processing* (2024) (cit. on p. 107).
- [52] A. J. Einstein, M. J. Henzlova, and S. Rajagopalan. “Estimating risk of cancer associated with radiation exposure from 64-slice computed tomography coronary angiography”. *Jama* 298.3 (2007), pp. 317–323 (cit. on p. 81).
- [53] I. A. Elbakri and J. A. Fessler. “Efficient and accurate likelihood for iterative image reconstruction in X-ray computed tomography”. In: *Medical Imaging 2003: Image Processing*. Vol. 5032. SPIE. 2003, pp. 1839–1850 (cit. on p. 85).
- [54] I. A. Elbakri and J. A. Fessler. “Statistical image reconstruction for polyenergetic X-ray computed tomography”. *IEEE transactions on medical imaging* 21.2 (2002), pp. 89–99 (cit. on p. 85).
- [55] H. W. Engl, M. Hanke-Bourgeois, and A. Neubauer. *Regularization of Inverse Problems*. Mathematics and Its Applications <Dordrecht> 375. Dordrecht: Kluwer Acad. Publ, 2000 (cit. on pp. 4, 105).
- [56] W. Ertel. *Introduction to artificial intelligence*. Springer Nature, 2024 (cit. on p. 13).
- [57] Ethan A Merritt. *X-ray Absorption Edges*. 1996-2010 (cit. on p. 34).
- [58] K Faulkner and B. Moores. “Noise and contrast detection in computed tomography images”. *Physics in Medicine & Biology* 29.4 (1984), p. 329 (cit. on p. 83).
- [59] L. Feldkamp, L. David, and J. Kress. “Practical cone-beam algorithm”. *J Opt Soc Am A* 1 (1984), pp. 612–619 (cit. on pp. 5, 6, 45).

- [60] D. Frank, J. Jelten, and T. Lasser. “elsa: an elegant framework for tomographic reconstruction”. *Journal of Open Source Software* 9.94 (2024), p. 6174 (cit. on p. 133).
- [61] P. Fried, J. Woodward, D. Brown, D. Harvell, and J. Hanken. “3D scanning of antique glass by combining photography and computed tomography”. *Digital Applications in Archaeology and Cultural Heritage* 18 (2020), e00147 (cit. on pp. 38, 49).
- [62] J. Friel and E. T. Quinto. “Characterization and reduction of artifacts in limited angle tomography”. *Inverse Problems* 29.12 (2013), p. 125007 (cit. on p. 109).
- [63] D. P. Frush, C. C. Slack, C. L. Hollingsworth, G. S. Bisset, L. F. Donnelly, J. Hsieh, T. Lavin-Wensell, and J. R. Mayo. “Computer-simulated radiation dose reduction for abdominal multidetector CT of pediatric patients”. *American Journal of Roentgenology* 179.5 (2002), pp. 1107–1113 (cit. on p. 84).
- [64] L. Fu and B. De Man. “Deep learning tomographic reconstruction through hierarchical decomposition of domain transforms”. *Visual Computing for Industry, Biomedicine, and Art* 5.1 (2022), p. 30 (cit. on p. 106).
- [65] F. Gao and L. Han. “Implementing the Nelder-Mead simplex algorithm with adaptive parameters”. *Computational Optimization and Applications* 51 (May 2012), pp. 259–277 (cit. on p. 75).
- [66] R. Garnett. “A comprehensive review of dual-energy and multi-spectral computed tomography”. *Clinical imaging* 67 (2020), pp. 160–169 (cit. on p. 3).
- [67] M. Genzel, J. Macdonald, and M. März. “Solving Inverse Problems With Deep Neural Networks – Robustness Included?” *IEEE Transactions on Pattern Analysis and Machine Intelligence* 45.1 (2022), pp. 1119–1134 (cit. on p. 124).
- [68] D. T. Ginat and R. Gupta. “Advances in computed tomography imaging technology”. *Annual Review of Biomedical Engineering* 16 (2014), pp. 431–453 (cit. on p. 103).
- [69] B. Girod. “Psychovisual aspects of image communication”. *Signal Processing* 28.3 (1992), pp. 239–251 (cit. on pp. 90, 111).
- [70] L. W. Goldman. “Principles of CT: Radiation Dose and Image Quality”. *Journal of Nuclear Medicine Technology* 35.4 (2007), pp. 213–225. eprint: <https://tech.snmjournals.org/content/35/4/213.full.pdf> (cit. on pp. 38, 70).
- [71] H. Gong, L. Ren, S. S. Hsieh, C. H. McCollough, and L. Yu. “Deep learning enabled ultra-fast-pitch acquisition in clinical x-ray computed tomography”. *Medical physics* 48.10 (2021), pp. 5712–5726 (cit. on p. 102).
- [72] I. Goodfellow, Y. Bengio, and A. Courville. *Deep learning*. MIT press, 2016 (cit. on p. 13).
- [73] D. Gourdeau, S. Duchesne, and L. Archambault. “On the proper use of structural similarity for the robust evaluation of medical image synthesis models”. *Medical Physics* 49.4 (2022), pp. 2462–2474 (cit. on p. 90).

- [74] K. Gregor and Y. LeCun. “Learning fast approximations of sparse coding”. In: *Proceedings of the 27th International Conference on Machine Learning*. 2010, pp. 399–406 (cit. on p. 106).
- [75] H. Gupta, K. H. Jin, H. Q. Nguyen, M. T. McCann, and M. Unser. “CNN-based projected gradient descent for consistent CT image reconstruction”. *IEEE Transactions on Medical Imaging* 37.6 (2018), pp. 1440–1453 (cit. on p. 106).
- [76] A. Habring and M. Holler. “Neural-network-based regularization methods for inverse problems in imaging”. *GAMM-Mitteilungen* (2024), e202470004 (cit. on p. 107).
- [77] H. Hamba, T. Nikaido, A. Sadr, S. Nakashima, and J. Tagami. “Enamel Lesion Parameter Correlations between Polychromatic Micro-CT and TMR”. *Journal of Dental Research* 91.6 (2012). PMID: 22476867, pp. 586–591 (cit. on pp. 30, 42).
- [78] Y. Han and J. C. Ye. “Framing U-Net via deep convolutional framelets: Application to sparse-view CT”. *IEEE Transactions on Medical Imaging* 37.6 (2018), pp. 1418–1429 (cit. on p. 106).
- [79] P. C. Hansen, J. Jørgensen, and W. R. B. Lionheart. *Computed Tomography: Algorithms, Insight, and Just Enough Theory*. Ed. by P. C. Hansen, J. Jørgensen, and W. R. B. Lionheart. Philadelphia, PA: Society for Industrial and Applied Mathematics, 2021 (cit. on pp. 2–4, 37, 113).
- [80] A. Hauptmann, S. Mukherjee, C.-B. Schönlieb, and F. Sherry. “Convergent Regularization in Inverse Problems and Linear Plug-and-Play Denoisers”. *Foundations of Computational Mathematics* (2024) (cit. on p. 107).
- [81] A. A. Hendriksen, D. Schut, W. J. Palenstijn, N. Viganó, J. Kim, D. M. Pelt, T. Van Leeuwen, and K. J. Batenburg. “Tomosipo: fast, flexible, and convenient 3D tomography for complex scanning geometries in Python”. *Optics Express* 29.24 (2021), pp. 40494–40513 (cit. on pp. 99, 110, 112).
- [82] J. Hsieh. “Adaptive streak artifact reduction in computed tomography resulting from excessive X-ray photon noise”. *Medical Physics* 25.11 (1998), pp. 2139–2147 (cit. on pp. 81, 84).
- [83] J. Hsieh. *Computed Tomography: Principles, Design, Artifacts, and Recent Advances*. Washington: SPIE press, 2003 (cit. on pp. 1, 37, 83).
- [84] J. Hsieh and T. Flohr. “Computed tomography recent history and future perspectives”. *Journal of Medical Imaging* 8.5 (2021), pp. 052109–052109 (cit. on p. 103).
- [85] S. Hurault, A. Leclaire, and N. Papadakis. “Gradient Step Denoiser for convergent Plug-and-Play”. In: *The Tenth International Conference on Learning Representations, ICLR 2022, Virtual Event, April 25-29, 2022*. OpenReview.net, 2022 (cit. on pp. 113, 114).
- [86] A. Jansson, J. Ekengren, A.-R. Zekavat, and L. Pejryd. “Effects of x-ray penetration depth on multi material computed tomography measurements”. In: *6th Conference on Industrial Computed Tomography*. 2016 (cit. on p. 38).

- [87] R. J. Jennings. “A method for comparing beam-hardening filter materials for diagnostic radiology”. *Medical physics* 15.4 (1988), pp. 588–599 (cit. on pp. 30, 42, 57, 130).
- [88] K. H. Jin, M. T. McCann, E. Froustey, and M. Unser. “Deep convolutional neural network for inverse problems in imaging”. *IEEE Transactions on Image Processing* 26.9 (2017), pp. 4509–4522 (cit. on pp. 102, 106).
- [89] P. M. Joseph and R. A. Schulz. “View sampling requirements in fan beam computed tomography”. *Medical Physics* 7.6 (1980), pp. 692–702 (cit. on pp. 7, 110, 117).
- [90] U. S. Kamilov, C. A. Bouman, G. T. Buzzard, and B. Wohlberg. “Plug-and-play methods for integrating physical and learned models in computational imaging: Theory, algorithms, and applications”. *IEEE Signal Processing Magazine* 40.1 (2023), pp. 85–97 (cit. on p. 107).
- [91] E. Kang, J. Min, and J. C. Ye. “A deep convolutional neural network using directional wavelets for low-dose X-ray CT reconstruction”. *Medical Physics* 44.10 (2017), e360–e375 (cit. on pp. 106, 133).
- [92] R. A. Ketcham and W. D. Carlson. “Acquisition, optimization and interpretation of X-ray computed tomographic imagery: applications to the geosciences”. *Computers & Geosciences* 27.4 (2001). 3D reconstruction, modelling & visualization of geological materials, pp. 381–400 (cit. on pp. 57, 130).
- [93] F. M. Khan and J. P. Gibbons. *Khan’s the physics of radiation therapy*. Philadelphia, PA: Lippincott Williams & Wilkins, 2014 (cit. on pp. 34, 43, 70).
- [94] F. Kharfi. “Mathematics and Physics of Computed Tomography (CT): Demonstrations and Practical Examples”. In: *Imaging and Radioanalytical Techniques in Interdisciplinary Research*. Ed. by F. Kharfi. Rijeka: IntechOpen, 2013. Chap. 4 (cit. on pp. 9, 33, 46, 71).
- [95] A. Khorashadizadeh, V. Debarnot, T. Liu, and I. Dokmanić. “GLIMPSE: Generalized Local Imaging with MLPs”. *arXiv preprint arXiv:2401.00816* (2024) (cit. on p. 125).
- [96] E. Kim, K. Muroi, T. Koike, and J. Kim. “Dose Reduction and Image Quality Optimization of Pediatric Chest Radiography Using a Tungsten Filter”. *Bioengineering* 9.10 (2022) (cit. on pp. 30, 42).
- [97] D. P. Kingma and J. Ba. “Adam: A method for stochastic optimization”. *arXiv preprint arXiv:1412.6980* (2014) (cit. on pp. 91, 115).
- [98] M. Kiss, S. Coban, K. Batenburg, T. van Leeuwen, and F. Lucka. “2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning”. *Scientific Data* 10.1 (2023), p. 576 (cit. on pp. 61, 82, 87, 102, 103, 109, 111, 112, 115, 118, 155).
- [99] M. B. Kiss, A. Biguri, C.-B. Schönlieb, K. J. Batenburg, and F. Lucka. “Learned denoising with simulated and experimental low-dose CT data”. *arXiv preprint arXiv:2408.08115* (2024) (cit. on pp. 81, 155).

- [100] M. B. Kiss, A. Biguri, Z. Shumaylov, F. Sherry, K. J. Batenburg, C.-B. Schönlieb, and F. Lucka. “Benchmarking learned algorithms for computed tomography image reconstruction tasks”. *Applied Mathematics for Modern Challenges* 3.0 (2025), pp. 1–43 (cit. on pp. 101, 155).
- [101] M. B. Kiss, F. G. Bossema, P. J. van Laar, S. Meijer, F. Lucka, T. van Leeuwen, and K. J. Batenburg. “Beam filtration for object-tailored X-ray CT of multi-material cultural heritage objects”. *Heritage Science* 11.1 (2023), p. 130 (cit. on pp. 37, 155).
- [102] M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices 1-1,000*. June 2023 (cit. on pp. 76, 82, 126, 155).
- [103] M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices 1-1,000 (reference reconstructions and segmentations)*. June 2023 (cit. on pp. 76, 82, 156).
- [104] M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices 1,001-2,000*. June 2023 (cit. on pp. 76, 82, 155).
- [105] M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices 1,001-2,000 (reference reconstructions and segmentations)*. June 2023 (cit. on pp. 76, 82, 156).
- [106] M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices 2,001-3,000*. June 2023 (cit. on pp. 76, 82, 155).
- [107] M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices 2,001-3,000 (reference reconstructions and segmentations)*. June 2023 (cit. on pp. 76, 82, 156).
- [108] M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices 3,001-4,000*. June 2023 (cit. on pp. 76, 82, 155).
- [109] M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices 3,001-4,000 (reference reconstructions and segmentations)*. June 2023 (cit. on pp. 76, 82, 156).

- [110] M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices 4,001-5,000*. June 2023 (cit. on pp. 76, 82, 155).
- [111] M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices 4,001-5,000 (reference reconstructions and segmentations)*. June 2023 (cit. on pp. 76, 82, 156).
- [112] M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices OOD*. June 2023 (cit. on pp. 76, 82, 155).
- [113] M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices OOD (reference reconstructions and segmentations)*. June 2023 (cit. on pp. 76, 82, 156).
- [114] M. B. Kiss, H. Der Sarkissian, and F. Lucka. *2DeteCT - Collection of Python scripts for loading, pre-processing, reconstructing and segmenting X-ray CT projection data of the 2DeteCT data collection*. <https://github.com/mbkiss/2DeteCTcodes/>. Accessed: 2025-09-26. June 2023 (cit. on p. 156).
- [115] A. Klein, S. Wallkötter, S. Silvester, A. Tanbakuchi, actions user, P. Müller, J. Nunez-Iglesias, M. Harfouche, Dennis, A. Lee, and et al. *imageio/imageio: v2.26.0*. Zenodo, Feb. 2023 (cit. on p. 77).
- [116] F. Knoll, J. Zbontar, A. Sriram, M. J. Muckley, M. Bruno, A. Defazio, M. Parente, K. J. Geras, J. Katsnelson, H. Chandarana, Z. Zhang, M. Drozdal, A. Romero, M. Rabbat, P. Vincent, J. Pinkerton, D. Wang, N. Yakubova, E. Owens, C. L. Zitnick, M. P. Recht, D. K. Sodickson, and Y. W. Lui. “fastMRI: A Publicly Available Raw k-Space and DICOM Dataset of Knee Images for Accelerated MR Image Reconstruction Using Machine Learning”. *Radiology: Artificial Intelligence* 2.1 (2020). PMID: 32076662, e190007. eprint: <https://doi.org/10.1148/ryai.2020190007> (cit. on pp. 62, 103).
- [117] E. Kobler, A. Effland, K. Kunisch, and T. Pock. “Total deep variation for linear inverse problems”. In: *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*. 2020, pp. 7549–7558 (cit. on pp. 113, 114, 116).
- [118] A. Kostenko, W. Palenstijn, S. Coban, A. Hendriksen, R. van Liere, and K. Batenburg. “Prototyping X-ray tomographic reconstruction pipelines with Flexbox”. *SoftwareX* 11 (2020), p. 100364 (cit. on pp. 45, 46).
- [119] A. Krizhevsky, G. Hinton, et al. “Learning multiple layers of features from tiny images”. <https://www.cs.toronto.edu/kriz/learning-features-2009-TR.pdf> (2009) (cit. on pp. 15, 101, 133).

- [120] S. Kuanar, V. Athitsos, D. Mahapatra, K. Rao, Z. Akhtar, and D. Dasgupta. “Low dose abdominal CT image reconstruction: an unsupervised learning based approach”. In: *2019 IEEE international conference on image processing (ICIP)*. IEEE. 2019, pp. 1351–1355 (cit. on p. 133).
- [121] G. M. Lasio, B. R. Whiting, and J. F. Williamson. “Statistical reconstruction for X-ray computed tomography using energy-integrating detectors”. *Physics in medicine & biology* 52.8 (2007), p. 2247 (cit. on pp. 84, 85).
- [122] Y. LeCun, Y. Bengio, and G. Hinton. “Deep learning”. *Nature* 521.7553 (2015), pp. 436–444 (cit. on pp. 13, 101).
- [123] Y. LeCun, L. Bottou, Y. Bengio, and P. Haffner. “Gradient-based learning applied to document recognition”. *Proceedings of the IEEE* 86.11 (1998), pp. 2278–2324 (cit. on pp. 15, 62, 101, 133).
- [124] J. Leuschner, M. Schmidt, D. O. Baguer, and P. Maass. “LoDoPaB-CT, a benchmark dataset for low-dose computed tomography reconstruction”. *Scientific Data* 8.1 (2021), pp. 1–12 (cit. on pp. 62, 85, 103).
- [125] J. Leuschner, M. Schmidt, P. S. Ganguly, V. Andriiashen, S. B. Coban, A. Denker, D. Bauer, A. Hadjifaradji, K. J. Batenburg, P. Maass, et al. “Quantitative comparison of deep learning-based image reconstruction methods for low-dose and sparse-angle CT applications”. *Journal of Imaging* 7.3 (2021), p. 44 (cit. on pp. 89, 102).
- [126] H. Li, J. Schwab, S. Antholzer, and M. Haltmeier. “NETT: Solving inverse problems with deep neural networks”. *Inverse Problems* 36.6 (2020), p. 065005 (cit. on pp. 102, 107).
- [127] T. Li, X. Li, J. Wang, J. Wen, H. Lu, J. Hsieh, and Z. Liang. “Nonlinear sinogram smoothing for low-dose X-ray CT”. *IEEE Transactions on Nuclear Science* 51.5 (2004), pp. 2505–2513 (cit. on pp. 81, 84).
- [128] H. Liao, W.-A. Lin, S. K. Zhou, and J. Luo. “ADN: artifact disentanglement network for unsupervised metal artifact reduction”. *IEEE Transactions on Medical Imaging* 39.3 (2019), pp. 634–643 (cit. on p. 133).
- [129] P.-S. Liao, T.-S. Chen, and P. C. Chung. “A Fast Algorithm for Multilevel Thresholding”. *J. Inf. Sci. Eng.* 17 (2001), pp. 713–727 (cit. on p. 75).
- [130] Z. Liao, S. Hu, M. Li, W. Chen, et al. “Noise estimation for single-slice sinogram of low-dose X-ray computed tomography using homogenous patch”. *Mathematical Problems in Engineering* 2012 (2012) (cit. on p. 84).
- [131] D. Limited. *X-ray Detector Product Specifications DEXELA 1512 CMOS*. June 2010 (cit. on pp. 25, 44, 64).
- [132] *LION - Learned Iterative Optimization Networks*. <https://github.com/Cambria/LION/>. Accessed: 2024-16-06. 2024 (cit. on p. 89).

- [133] J. Liu, R. Anirudh, J. J. Thiagarajan, S. He, K. A. Mohan, U. S. Kamilov, and H. Kim. “DOLCE: A model-based probabilistic diffusion framework for limited-angle ct reconstruction”. In: *Proceedings of the IEEE/CVF International Conference on Computer Vision*. 2023, pp. 10498–10508 (cit. on pp. 114, 133).
- [134] S. Lunz, O. Öktem, and C.-B. Schönlieb. “Adversarial Regularizers in Inverse Problems”. In: *Advances in Neural Information Processing Systems*. Ed. by S. Bengio, H. Wallach, H. Larochelle, K. Grauman, N. Cesa-Bianchi, and R. Garnett. Vol. 31. Curran Associates, Inc., 2018 (cit. on p. 113).
- [135] V. Macchi, E. Picardi, A. Porzionato, A. Morra, L. Tabarin, F. Gusella, B. Grignon, and R. Caro. “Friar Leopold Mandic (1866–1942): the computed tomography of the body of a saint”. *Surgical and Radiologic Anatomy* 40 (Aug. 2018), pp. 1–9 (cit. on p. 38).
- [136] S. Maruyama. “Properties of the SSIM metric in medical image assessment: correspondence between measurements and the spatial frequency spectrum”. *Physical and Engineering Sciences in Medicine* 46.3 (2023), pp. 1131–1141 (cit. on p. 90).
- [137] P. Massoumzadeh, S. Don, C. F. Hildebolt, K. T. Bae, and B. R. Whiting. “Validation of CT dose-reduction simulation”. *Medical physics* 36.1 (2009), pp. 174–189 (cit. on pp. 84, 85).
- [138] P. Massoumzadeh, O. A. Earl, and B. R. Whiting. “Noise simulation in X-ray CT”. In: *Medical Imaging 2005: Physics of Medical Imaging*. Vol. 5745. SPIE. 2005, pp. 898–909 (cit. on pp. 84, 85).
- [139] MATLAB. *version 7.10.0 (R2010a)*. Natick, Massachusetts: The MathWorks Inc., 2010 (cit. on p. 77).
- [140] J. R. Mayo, K. P. Whittall, A. N. Leung, T. E. Hartman, C. S. Park, S. L. Primack, G. K. Chambers, M. K. Limkeman, T. L. Toth, and S. H. Fox. “Simulated dose reduction in conventional chest CT: validation study.” *Radiology* 202.2 (1997), pp. 453–457 (cit. on pp. 81, 84).
- [141] C McCollough. “TU-FG-207A-04: overview of the low dose CT grand challenge”. *Medical physics* 43.6Part35 (2016), pp. 3759–3760 (cit. on pp. 62, 85, 103, 104).
- [142] A. Meloni, F. Frijia, D. Panetta, G. Degiorgi, C. De Gori, E. Maffei, A. Clemente, V. Positano, and F. Cademartiri. “Photon-Counting Computed Tomography (PCCT): Technical Background and Cardio-Vascular Applications”. *Diagnostics* 13.4 (2023) (cit. on p. 41).
- [143] F. Mihanović, I. Jerković, I. Kružić, S. Andjelinović, S. Janković, and Ž. Bašić. “From Biography to Osteobiography: An Example of Anthropological Historical Identification of the Remains of St. Paul”. *The Anatomical Record* 300.9 (2017), pp. 1535–1546 (cit. on p. 38).
- [144] T. R. Moen, B. Chen, D. R. Holmes III, X. Duan, Z. Yu, L. Yu, S. Leng, J. G. Fletcher, and C. H. McCollough. “Low-dose CT image and projection dataset”. *Medical physics* 48.2 (2021), pp. 902–911 (cit. on pp. 62, 85, 103, 104).

- [145] V. Monga, Y. Li, and Y. C. Eldar. “Algorithm unrolling: Interpretable, efficient deep learning for signal and image processing”. *IEEE Signal Processing Magazine* 38.2 (2021), pp. 18–44 (cit. on p. 106).
- [146] L. Montaina, S. Longo, G. Galotta, G. Tranquilli, R. Saccuman, and S. Capuani. “Assessment of the panel support of a seventeenth-century Dutch painting by clinical multislice computed tomography”. *Studies in Conservation* 66.3 (2021), pp. 174–181 (cit. on p. 38).
- [147] S Mukherjee, S Dittmer, Z Shumaylov, S Lunz, O Öktem, and C.-B. Schönlieb. “Data-Driven Convex Regularizers for Inverse Problems”. In: *ICASSP 2024-2024 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*. IEEE. 2024, pp. 13386–13390 (cit. on pp. 113, 114).
- [148] S. Mukherjee, S. Dittmer, Z. Shumaylov, S. Lunz, O. Öktem, and C.-B. Schönlieb. “Learned convex regularizers for inverse problems”. *arXiv preprint arXiv:2008.02839* (2020) (cit. on pp. 113, 114, 116).
- [149] S. Mukherjee, A. Hauptmann, O. Öktem, M. Pereyra, and C.-B. Schönlieb. “Learned reconstruction methods with convergence guarantees: a survey of concepts and applications”. *IEEE Signal Processing Magazine* 40.1 (2023), pp. 164–182 (cit. on p. 107).
- [150] F. Natterer. *The mathematics of computerized tomography*. SIAM, 2001 (cit. on p. 5).
- [151] Y. E. Nesterov. “A method of solving a convex programming problem with convergence rate $O(k^2)$ ”. In: *Doklady Akademii Nauk*. Vol. 269. Russian Academy of Sciences. 1983, pp. 543–547 (cit. on pp. 74, 112, 113).
- [152] S. I. Nikolenko. “Synthetic-to-real domain adaptation and refinement”. In: *Synthetic data for deep learning*. Springer, 2021, pp. 235–268 (cit. on pp. 15, 99, 102).
- [153] D. Nykonenko, O. Yatsuk, L. Guidorzi, A. Lo Giudice, F. Tansella, L. P. Cesareo, G. Sorrentino, P. Davit, M. Gulmini, and A. Re. “Glass beads from a Scythian grave on the island of Khortytsia (Zaporizhzhia, Ukraine): insights into bead making through 3D imaging”. *Heritage Science* 11.1 (2023), p. 238 (cit. on p. 132).
- [154] W. Palenstijn, K. Batenburg, and J. Sijbers. “Performance improvements for iterative electron tomography reconstruction using graphics processing units (GPUs)”. *Journal of Structural Biology* 176.2 (2011), pp. 250–253 (cit. on pp. 99, 110, 112).
- [155] X. Pan, E. Y. Sidky, and M. Vannier. “Why do commercial CT scanners still employ traditional, filtered back-projection for image reconstruction?” *Inverse problems* 25.12 (2009), p. 123009 (cit. on p. 83).
- [156] X. Pan, J. Siewerdsen, P. J. La Riviere, and W. A. Kalender. “Anniversary Paper: Development of x-ray computed tomography: The role of Medical Physics and AAPM from the 1970s to present”. *Medical Physics* 35.8 (2008), pp. 3728–3739 (cit. on p. 38).

- [157] H. S. Park, S. M. Lee, H. P. Kim, J. K. Seo, and Y. E. Chung. “CT sinogram-consistency learning for metal-induced beam hardening correction”. *Medical Physics* 45.12 (2018), pp. 5376–5384 (cit. on p. 102).
- [158] J. A. Patton and T. G. Turkington. “SPECT/CT physical principles and attenuation correction”. *Journal of Nuclear Medicine Technology* 36.1 (2008), pp. 1–10 (cit. on pp. 11, 40, 69, 110, 118).
- [159] D. M. Pelt, K. J. Batenburg, and J. A. Sethian. “Improving tomographic reconstruction from limited data using mixed-scale dense convolutional neural networks”. *Journal of Imaging* 4.11 (2018), p. 128 (cit. on p. 89).
- [160] D. M. Pelt and J. A. Sethian. “A mixed-scale dense convolutional neural network for image analysis”. *Proceedings of the National Academy of Sciences* 115.2 (2018), pp. 254–259 (cit. on pp. 21, 82, 89, 91, 113).
- [161] A. N. Primak, J. C. R. Giraldo, C. D. Eusemann, B. Schmidt, B. Kantor, J. G. Fletcher, and C. H. McCollough. “Dual-source dual-energy CT with additional tin filtration: Dose and image quality evaluation in phantoms and in-vivo”. *AJR. American journal of roentgenology* 195.5 (2010), p. 1164 (cit. on p. 70).
- [162] T. Prohaszka, L. Neumann, and M. Haltmeier. “Derivative-Free Iterative One-Step Reconstruction for Multispectral CT”. *Journal of Imaging* 10.5 (2024), p. 98 (cit. on p. 132).
- [163] J. Radon. “1.1 über die bestimmung von funktionen durch ihre integralwerte längs gewisser mannigfaltigkeiten”. *Classic papers in modern diagnostic radiology* 5.21 (2005), p. 124 (cit. on p. 4).
- [164] J. Radon. “On the determination of functions from their integral values along certain manifolds”. *IEEE transactions on medical imaging* 5.4 (1986), pp. 170–176 (cit. on p. 4).
- [165] G. Ramachandran and A. Lakshminarayanan. “Three-dimensional reconstruction from radiographs and electron micrographs: application of convolutions instead of Fourier transforms”. *Proceedings of the National Academy of Sciences* 68.9 (1971), pp. 2236–2240 (cit. on p. 4).
- [166] S. Ravishankar, J. C. Ye, and J. A. Fessler. “Image reconstruction: From sparsity to data-adaptive methods and machine learning”. *Proceedings of the IEEE* 108.1 (2019), pp. 86–109 (cit. on pp. 16, 61, 106).
- [167] A. Re, F. Albertin, C. Avataneo, R. Brancaccio, G. Corsi J. ad Cotto, S. De Blasi, G. Dughera, E. Durisi, W. Ferrarese, A. Giovagnoli, N. Grassi, A. Lo Giudice, P. Mereu, G. Mila, M. Nervo, N. Pastrone, F. Prino, L. Ramello, M. Ravera, C. Ricci, A. Romero, R. Sacchi, A. Staiano, L. Visca, and L. Zamprotta. “X-ray tomography of large wooden artworks: the case study of “Doppio corpo” by Pietro Piffetti”. *Heritage Science* 2 (2014), p. 19 (cit. on p. 38).

- [168] J. Reid, J. Gamberoni, F. Dong, and W. Davros. “Optimization of kVp and mAs for Pediatric Low-Dose Simulated Abdominal CT: Is It Best to Base Parameter Selection on Object Circumference?” *American Journal of Roentgenology* 195.4 (2010). PMID: 20858833, pp. 1015–1020. eprint: <https://doi.org/10.2214/AJR.09.3862> (cit. on pp. 71, 118).
- [169] Rijksmuseum Amsterdam. *BK-KOG-29 - Beurs van groen fluweel met trekkoord en afgezet met gouddraad op een doosje in de vorm van een schaar (fallus?) van dito fluweel en passement, voorzien van twee metalen ogen*. na 1580 (cit. on pp. 46, 47).
- [170] Rijksmuseum Amsterdam. *BK-NM-3086 - Langwerpig, taps toelopend foedraal met dop, van leer verdeeld in drie compartimenten, bekleed met paars fluweel en geborduurd met goud- en zilverdraad, zoetwaterparels, en zilveren lovers*. c. 1600 - c. 1625 (cit. on pp. 46, 47).
- [171] E. L. Ritman. “Current status of developments and applications of micro-CT”. *Annual Review of Biomedical Engineering* 13 (2011), pp. 531–552 (cit. on p. 103).
- [172] Á. Rodríguez-Sánchez, A. Thompson, L. Körner, N. Brierley, and R. Leach. “Review of the influence of noise in X-ray computed tomography measurement uncertainty”. *Precision Engineering* 66 (2020), pp. 382–391 (cit. on pp. 33, 88).
- [173] O. Ronneberger, P. Fischer, and T. Brox. “U-net: Convolutional networks for biomedical image segmentation”. In: *Medical Image Computing and Computer-Assisted Intervention—MICCAI 2015: 18th International Conference, Munich, Germany, October 5-9, 2015, Proceedings, Part III* 18. Springer, 2015, pp. 234–241 (cit. on pp. 82, 89, 113).
- [174] M. Salamon, M. Arzig, P. J. Wellmann, and N. Uhlmann. “Comparison of achievable contrast features in computed tomography observing the growth of a 4H-SiC bulk crystal”. *Materials* 12.22 (2019), p. 3652 (cit. on p. 41).
- [175] A. L. Samuel. “Some studies in machine learning using the game of checkers”. *IBM Journal of research and development* 3.3 (1959), pp. 210–229 (cit. on p. 13).
- [176] O. Scherzer, M. Grasmair, H. Grossauer, M. Haltmeier, and F. Lenzen. *Variational Methods in Imaging*. Springer, 2009 (cit. on pp. 4, 105, 124).
- [177] C. A. Schneider, W. S. Rasband, and K. W. Eliceiri. “NIH Image to ImageJ: 25 years of image analysis”. *Nature methods* 9.7 (2012), pp. 671–675 (cit. on p. 77).
- [178] M. Seracini, M. Bettuzzi, R. Brancaccio, and M. P. Morigi. “Calibration-free 3D ray-tracing beam hardening correction in computed tomography”. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 1062 (2024), p. 169226 (cit. on p. 132).

- [179] H. Shan, A. Padole, F. Homayounieh, U. Kruger, R. D. Khera, C. Nitiwarangkul, M. K. Kalra, and G. Wang. “Competitive performance of a modularized deep neural network compared to commercial algorithms for low-dose CT image reconstruction”. *Nature Machine Intelligence* 1.6 (2019), pp. 269–276 (cit. on p. 102).
- [180] H. R. Sheikh, M. F. Sabir, and A. C. Bovik. “A statistical evaluation of recent full reference image quality assessment algorithms”. *IEEE Transactions on image processing* 15.11 (2006), pp. 3440–3451 (cit. on p. 111).
- [181] J. Shi, O. Elkilany, A. Fischer, A. Suppes, D. M. Pelt, and K. J. Batenburg. “LoDoInd: Introducing A Benchmark Low-dose Industrial CT Dataset and Enhancing Denoising with 2.5 D Deep Learning Techniques”. *preprint* (2024) (cit. on p. 133).
- [182] Z. Shumaylov, J. Budd, S. Mukherjee, and C.-B. Schönlieb. “Provably Convergent Data-Driven Convex-Nonconvex Regularization”. In: *NeurIPS 2023 Workshop on Deep Learning and Inverse Problems*. 2023 (cit. on p. 5).
- [183] Z. Shumaylov, J. Budd, S. Mukherjee, and C.-B. Schönlieb. *Weakly Convex Regularisers for Inverse Problems: Convergence of Critical Points and Primal-Dual Optimisation*. arXiv:2402.01052. 2024. arXiv: 2402.01052 [math.OA] (cit. on p. 107).
- [184] S. S. Skiena. *The data science design manual*. Springer, 2017 (cit. on p. 15).
- [185] N. Sodini, D. Dreossi, A. Giordano, J. Kaiser, F. Zanini, and T. Zikmund. “Comparison of different experimental approaches in the tomographic analysis of ancient violins”. *Journal of Cultural Heritage* 27 (2017), S88–S92 (cit. on p. 38).
- [186] Y. Song, L. Shen, L. Xing, and S. Ermon. “Solving Inverse Problems in Medical Imaging with Score-Based Generative Models”. In: *International Conference on Learning Representations*. 2022 (cit. on pp. 114, 133).
- [187] J. Tachella, D. Chen, S. Hurault, M. Terris, and A. Wang. *DeepInverse: A deep learning framework for inverse problems in imaging*. Version latest. June 2023 (cit. on p. 110).
- [188] M. F. Tarplee and N. Corps. “Acquiring optimal quality X-ray μ CT scans”. *Application note* 1 (2008), pp. 93–99 (cit. on p. 42).
- [189] E. Valat, A. Hauptmann, and O. Öktem. “Self-Supervised Denoiser Framework”. *arXiv preprint arXiv:2411.19593* (2024) (cit. on p. 133).
- [190] W. van Aarle, W. J. Palenstijn, J. De Beenhouwer, T. Altantzis, S. Bals, K. J. Batenburg, and J. Sijbers. “The ASTRA Toolbox: A platform for advanced algorithm development in electron tomography”. *Ultramicroscopy* 157 (2015), pp. 35–47 (cit. on pp. 99, 110, 112).
- [191] G. Van Rossum and F. L. Drake Jr. *Python reference manual*. Centrum voor Wiskunde en Informatica Amsterdam, 1995 (cit. on p. 77).

- [192] M. Vandenbeusch and B. O’Flynn D. abd Moreno. “Layer by Layer: The Manufacture of Graeco-Roman Funerary Masks”. *The Journal of Egyptian Archaeology* 107 (2021), 281–98 (cit. on p. 38).
- [193] A. Vandivere, J. Wadum, K. J. Van den Berg, and A. van Loon. “From ‘Vermeer Illuminated’ to ‘The Girl in the Spotlight’: approaches and methodologies for the scientific (re-)examination of Vermeer’s Girl with a Pearl Earring”. *Heritage Science* 7 (Aug. 2019), pp. 1–14 (cit. on p. 38).
- [194] S. V. Venkatakrishnan, C. A. Bouman, and B. Wohlberg. “Plug-and-play priors for model based reconstruction”. In: *2013 IEEE Global Conference on Signal and Information Processing*. IEEE. 2013, pp. 945–948 (cit. on p. 107).
- [195] A. K. Venkataramanan, C. Wu, A. C. Bovik, I. Katsavounidis, and Z. Shahid. “A hitchhiker’s guide to structural similarity”. *IEEE Access* 9 (2021), pp. 28872–28896 (cit. on p. 111).
- [196] H. Villarraga-Gómez, E. Herazo, and S. Smith. “X-ray computed tomography: from medical imaging to dimensional metrology”. *Precision Engineering* 60 (Nov. 2019), pp. 544–569 (cit. on p. 37).
- [197] C. Wang, K. Shang, H. Zhang, Q. Li, and S. K. Zhou. “DuDoTrans: dual-domain transformer for sparse-view CT reconstruction”. In: *International Workshop on Machine Learning for Medical Image Reconstruction*. Springer. 2022, pp. 84–94 (cit. on p. 133).
- [198] D. Wang, F. Fan, Z. Wu, R. Liu, F. Wang, and H. Yu. “CTformer: convolution-free Token2Token dilated vision transformer for low-dose CT denoising”. *Physics in Medicine & Biology* 68.6 (2023), p. 065012 (cit. on pp. 114, 133).
- [199] G. Wang, J. C. Ye, K. Mueller, and J. A. Fessler. “Image reconstruction is a new frontier of machine learning”. *IEEE Transactions on Medical Imaging* 37.6 (2018), pp. 1289–1296 (cit. on pp. 102, 103).
- [200] G. Wang, H. Yu, and B. De Man. “An outlook on x-ray CT research and development”. *Medical Physics* 35.3 (2008), pp. 1051–1064 (cit. on p. 103).
- [201] Z. Wang, Z. Deng, F. Liu, Y. Huang, H. Yu, and J. Cui. “OSNet & MNetO: Two Types of General Reconstruction Architectures to Transform DBP Images for Linear Computed Tomography in Multi-Scenarios”. *IEEE Transactions on Instrumentation and Measurement* (2024) (cit. on p. 133).
- [202] Z. Wang, A. C. Bovik, H. R. Sheikh, and E. P. Simoncelli. “Image quality assessment: from error visibility to structural similarity”. *IEEE transactions on image processing* 13.4 (2004), pp. 600–612 (cit. on pp. 90, 111).
- [203] G. Webber and A. J. Reader. “Diffusion models for medical image reconstruction”. *BJR/ Artificial Intelligence* 1.1 (2024), ubae013 (cit. on p. 107).
- [204] L. M. Weber, W. Saelens, R. Cannoodt, C. Sonesson, A. Hapfelmeier, P. P. Gardner, A.-L. Boulesteix, Y. Saeyns, and M. D. Robinson. “Essential guidelines for computational method benchmarking”. *Genome Biology* 20 (2019), pp. 1–12 (cit. on p. 107).

- [205] M. Weiss, N. Brierley, M. von Schmid, and T. Meisen. “Simulation Study: Data-Driven Material Decomposition in Industrial X-ray Computed Tomography”. *NDT 2.1* (2024), pp. 1–15 (cit. on pp. 15, 99, 102).
- [206] B. R. Whiting. “Signal statistics in X-ray computed tomography”. In: *Medical Imaging 2002: Physics of Medical Imaging*. Vol. 4682. SPIE. 2002, pp. 53–60 (cit. on pp. 84, 85).
- [207] B. R. Whiting, P. Massoumzadeh, O. A. Earl, J. A. O’Sullivan, D. L. Snyder, and J. F. Williamson. “Properties of preprocessed sinogram data in X-ray computed tomography”. *Medical physics* 33.9 (2006), pp. 3290–3303 (cit. on pp. 78, 82, 84, 85).
- [208] B. R. Whiting and E. Muka. “Image quantization: statistics and modeling”. In: *Medical Imaging 1998: Physics of Medical Imaging*. Vol. 3336. SPIE. 1998, pp. 260–271 (cit. on pp. 84, 85).
- [209] P. Wilson, M. Smith, J. Hay, J. Warnett, A. Attridge, and M. Williams. “X-ray computed tomography (XCT) and chemical analysis (EDX and XRF) used in conjunction for cultural conservation: the case of the earliest scientifically described dinosaur *Megalosaurus bucklandii*”. *Heritage Science* 6 (Oct. 2018) (cit. on p. 38).
- [210] J. M. Wolterink, T. Leiner, M. A. Viergever, and I. Išgum. “Generative adversarial networks for noise reduction in low-dose CT”. *IEEE transactions on medical imaging* 36.12 (2017), pp. 2536–2545 (cit. on p. 133).
- [211] D. Wu, H. Ren, and Q. Li. “Self-supervised dynamic CT perfusion image denoising with deep neural networks”. *IEEE Transactions on Radiation and Plasma Medical Sciences* 5.3 (2020), pp. 350–361 (cit. on p. 133).
- [212] M. Wu, P. FitzGerald, J. Zhang, W. P. Segars, H. Yu, Y. Xu, and B. De Man. “XCIST—an open access X-ray/CT simulation toolkit”. *Physics in Medicine & Biology* 67.19 (2022), p. 194002 (cit. on pp. 85, 89).
- [213] T. Würfl, M. Hoffmann, V. Christlein, K. Breininger, Y. Huang, M. Unberath, and A. K. Maier. “Deep learning computed tomography: Learning projection-domain weights from image domain in limited angle problems”. *IEEE Transactions on Medical Imaging* 37.6 (2018), pp. 1454–1463 (cit. on p. 102).
- [214] W. Xia, Z. Yang, Q. Zhou, Z. Lu, Z. Wang, and Y. Zhang. “A transformer-based iterative reconstruction model for sparse-view ct reconstruction”. In: *International Conference on Medical Image Computing and Computer-Assisted Intervention*. Springer. 2022, pp. 790–800 (cit. on p. 133).
- [215] L. Xing, E. A. Krupinski, and J. Cai. “Artificial intelligence will soon change the landscape of medical physics research and practice”. *Medical physics* 45.5 (2018), p. 1791 (cit. on p. 13).
- [216] XRE TESCAN. *TESCAN micro-CT webpage*. 2023 (cit. on pp. 25, 43).

- [217] J. Xu and B. M. Tsui. “Electronic noise modeling in statistical iterative reconstruction”. *IEEE Transactions on Image Processing* 18.6 (2009), pp. 1228–1238 (cit. on p. 85).
- [218] Q. Yang, P. Yan, Y. Zhang, H. Yu, Y. Shi, X. Mou, M. K. Kalra, Y. Zhang, L. Sun, and G. Wang. “Low-dose CT image denoising using a generative adversarial network with Wasserstein distance and perceptual loss”. *IEEE Transactions on Medical Imaging* 37.6 (2018), pp. 1348–1357 (cit. on p. 102).
- [219] J. C. Ye, Y. C. Eldar, and M. A. Unser. *Deep Learning for Biomedical Image Reconstruction*. Cambridge University Press, 2023 (cit. on pp. 16, 106, 108).
- [220] H. Yu, C. Liu, M. Thies, F. Wagner, A. Wang, G. Zhang, Y. Huang, F. Liu, and A. Maier. “Reducing penumbral blur in computed tomography by learning the inverse finite focal spot model”. *Optics Express* 32.13 (2024), pp. 23674–23686 (cit. on p. 133).
- [221] L. Yu, M. Shiung, D. Jondal, and C. H. McCollough. “Development and validation of a practical lower-dose-simulation tool for optimizing computed tomography scan protocols”. *Journal of computer assisted tomography* 36.4 (2012), pp. 477–487 (cit. on p. 83).
- [222] S. Zabić, Q. Wang, T. Morton, and K. M. Brown. “A low dose simulation tool for CT systems with energy integrating detectors”. *Medical physics* 40.3 (2013), p. 031102 (cit. on p. 85).
- [223] E. Zainulina, A. Chernyavskiy, and D. V. Dylov. “Self-supervised Physics-based Denoising for Computed Tomography”. *arXiv preprint arXiv:2211.00745* (2022) (cit. on pp. 84, 87).
- [224] D. Zeng, J. Huang, Z. Bian, S. Niu, H. Zhang, Q. Feng, Z. Liang, and J. Ma. “A simple low-dose X-ray CT simulation from high-dose scan”. *IEEE transactions on nuclear science* 62.5 (2015), pp. 2226–2233 (cit. on p. 90).
- [225] H.-M. Zhang and B. Dong. “A review on deep learning in medical image reconstruction”. *Journal of the Operations Research Society of China* 8 (2020), pp. 311–340 (cit. on pp. 15, 106, 125, 132).
- [226] K. Zhang, Y. Li, W. Zuo, L. Zhang, L. Van Gool, and R. Timofte. “Plug-and-Play Image Restoration With Deep Denoiser Prior”. *IEEE Transactions on Pattern Analysis and Machine Intelligence* 44.10 (2022), pp. 6360–6376 (cit. on pp. 113, 114).
- [227] K. Zhang, W. Zuo, Y. Chen, D. Meng, and L. Zhang. “Beyond a Gaussian denoiser: Residual learning of deep CNN for image denoising”. *IEEE Transactions on Image Processing* 26.7 (2017), pp. 3142–3155 (cit. on pp. 113, 114).
- [228] Z. Zhang, X. Liang, X. Dong, Y. Xie, and G. Cao. “A sparse-view CT reconstruction method based on combination of DenseNet and deconvolution”. *IEEE Transactions on Medical Imaging* 37.6 (2018), pp. 1407–1417 (cit. on p. 106).

-
- [229] Z. Zhang, L. Yu, X. Liang, W. Zhao, and L. Xing. “TransCT: dual-path transformer for low dose computed tomography”. In: *Medical Image Computing and Computer Assisted Intervention–MICCAI 2021: 24th International Conference, Strasbourg, France, September 27–October 1, 2021, Proceedings, Part VI 24*. Springer. 2021, pp. 55–64 (cit. on p. 133).
- [230] B. Zhu, J. Z. Liu, S. F. Cauley, B. R. Rosen, and M. S. Rosen. “Image reconstruction by domain-transform manifold learning”. *Nature* 555.7697 (2018), pp. 487–492 (cit. on pp. 16, 106).
- [231] E. A. Zwanenburg, M. A. Williams, and J. M. Warnett. “Review of high-speed imaging with lab-based x-ray computed tomography”. *Measurement Science and Technology* 33.1 (Nov. 2021), p. 012003 (cit. on p. 39).

List of publications

Publications that are part of this thesis:

1. M. B. Kiss, F. G. Bossema, P. J. van Laar, S. Meijer, F. Lucka, T. van Leeuwen, and K. J. Batenburg. “Beam filtration for object-tailored X-ray CT of multi-material cultural heritage objects”. *Heritage Science* 11.1 (2023), p. 130.
2. M. Kiss, S. Coban, K. Batenburg, T. van Leeuwen, and F. Lucka. “2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning”. *Scientific Data* 10.1 (2023), p. 576.
3. M. B. Kiss, A. Biguri, C.-B. Schönlieb, K. J. Batenburg, and F. Lucka. “Learned denoising with simulated and experimental low-dose CT data”. *arXiv preprint arXiv:2408.08115* (2024).
4. M. B. Kiss, A. Biguri, Z. Shumaylov, F. Sherry, K. J. Batenburg, C.-B. Schönlieb, and F. Lucka. “Benchmarking learned algorithms for computed tomography image reconstruction tasks”. *Applied Mathematics for Modern Challenges* 3.0 (2025), pp. 1–43.

Published datasets and code related to this thesis:

1. M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices 1-1,000*. June 2023
2. M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices 1,001-2,000*. June 2023
3. M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices 2,001-3,000*. June 2023
4. M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices 3,001-4,000*. June 2023
5. M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices 4,001-5,000*. June 2023
6. M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices OOD*. June 2023

7. M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices 1-1,000 (reference reconstructions and segmentations)*. June 2023
8. M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices 1,001-2,000 (reference reconstructions and segmentations)*. June 2023
9. M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices 2,001-3,000 (reference reconstructions and segmentations)*. June 2023
10. M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices 3,001-4,000 (reference reconstructions and segmentations)*. June 2023
11. M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices 4,001-5,000 (reference reconstructions and segmentations)*. June 2023
12. M. B. Kiss, S. B. Coban, K. J. Batenburg, T. van Leeuwen, and F. Lucka. *2DeteCT - A large 2D expandable, trainable, experimental Computed Tomography dataset for machine learning: Slices OOD (reference reconstructions and segmentations)*. June 2023
13. M. B. Kiss, H. Der Sarkissian, and F. Lucka. *2DeteCT - Collection of Python scripts for loading, pre-processing, reconstructing and segmenting X-ray CT projection data of the 2DeteCT data collection*. <https://github.com/mbkiss/2DeteCTcodes/>. Accessed: 2025-09-26. June 2023