



Universiteit
Leiden
The Netherlands

Solving the gravitational N-body problem with machine learning

Saz Ulibarrena, V.

Citation

Saz Ulibarrena, V. (2025, October 7). *Solving the gravitational N-body problem with machine learning*. Retrieved from <https://hdl.handle.net/1887/4262580>

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/1887/4262580>

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

BIBLIOGRAPHY

- Aarseth, S. A. 2003, *Gravitational N-body Simulations* (Cambridge University press, 2003)
- Aarseth, S. J. 1985, in *Multiple time scales* (Elsevier), 377–418
- Aarseth, S. J. & Lecar, M. 1975, *Annual Review of Astronomy and Astrophysics*, 13, 1
- Abadi, M., Agarwal, A., Barham, P., et al. 2015, *TensorFlow: Large-Scale Machine Learning on Heterogeneous Systems*, software available from tensorflow.org
- Almojel, A. I. 2000, *Computers & Electrical Engineering*, 26, 297
- Americo, M. 2017, *The Classical Outlook*, 92, 94
- Antonion, K., Wang, X., Raissi, M., & Joshie, L. 2024, *Academic Journal of Science and Technology*, 9, 46
- Barnes, J. & Hut, P. 1986, *nature*, 324, 446
- Basuchoudhary, A., Bang, J. T., & Sen, T. 2017, *Machine-learning Techniques in Economics: New Tools for Predicting Economic Growth* (Springer)
- Belkin, S. & Kuznetsov, E. 2021, *Acta Astronautica*, 178, 360
- Boekholt, T. & Portegies Zwart, S. 2015a, *Computational Astrophysics and Cosmology*, 2, 2
- Boekholt, T. & Portegies Zwart, S. 2015b, *Computational Astrophysics and Cosmology*, 2, 1
- Boekholt, T. & Portegies Zwart, S. 2015, *Computational Astrophysics and Cosmology*, 2, 1
- Boekholt, T. & Portegies Zwart, S. 2015, *Computational Astrophysics and Cosmology*, 2, 2
- Breen, P. G., Foley, C. N., Boekholt, T., & Portegies Zwart, S. 2020a, *Monthly Notices of the Royal Astronomical Society*, 494, 2465
- Breen, P. G., Foley, C. N., Boekholt, T., & Portegies Zwart, S. 2020b, *Monthly Notices of the Royal Astronomical Society*, 494, 2465

- Brockman, G., Cheung, V., Pettersson, L., et al. 2016a, arXiv preprint arXiv:1606.01540
- Brockman, G., Cheung, V., Pettersson, L., et al. 2016b, OpenAI Gym
- Burby, J., Tang, Q., & Maulik, R. 2021, *Plasma Physics and Controlled Fusion*, 63, 024001
- Cai, M. X., Portegies Zwart, S., & Podareanu, D. 2021a, arXiv preprint arXiv:2111.15631
- Cai, S., Wang, Z., Wang, S., Perdikaris, P., & Karniadakis, G. E. 2021b, *Journal of Heat Transfer*, 143, 060801
- Capuzzo-Dolcetta, R., Spera, M., & Punzo, D. 2013, *Journal of Computational Physics*, 236, 580
- Chen, R. & Tao, M. 2021, arXiv preprint arXiv:2103.05632
- Chen, R. T. Q., Rubanova, Y., Bettencourt, J., & Duvenaud, D. 2018, in *Advances in Neural Information Processing Systems*, Vol. 31 (Curran Associates, Inc.)
- Chen, Z., Zhang, J., Arjovsky, M., & Bottou, L. 2020, in *8th International Conference on Learning Representations, ICLR 2020*
- Chevallier, F., Chéruy, F., Scott, N., & Chédin, A. 1998, *Journal of Applied Meteorology*, 37, 1385
- Copernicus, N. 1543, *On the Revolutions of the Heavenly Spheres* (Princeton University Press)
- Coronato, A., Naeem, M., De Pietro, G., & Paragliola, G. 2020, *Artificial Intelligence in Medicine*, 109, 101964
- Curtis, H. D. 2019, *Orbital mechanics for engineering students* (Butterworth-Heinemann)
- Dayan, P. & Niv, Y. 2008, *Current opinion in neurobiology*, 18, 185
- Dellnitz, M., Hüllermeier, E., Lücke, M., et al. 2023, *SIAM Journal on Scientific Computing*, 45, A579
- Doupe, P., Faghmous, J., & Basu, S. 2019, *Value in Health*, 22, 808
- E, W. 2017, *Communications in Mathematics and Statistics*, 5, 1
- Easton, R. W. 1993, *SIAM Review*, 35, 659
- Elipe, A., Montijano, J., Rández, L., & Calvo, M. 2017, *Celestial Mechanics and Dynamical Astronomy*, 129, 415
- Farea, A., Yli-Harja, O., & Emmert-Streib, F. 2024, *AI*, 5, 1534
- Fujii, M., Iwasawa, M., Funato, Y., & Makino, J. 2007, *Publications of the Astronomical Society of Japan*, 59, 1095

- Glorot, X. & Bengio, Y. 2010, in Proceedings of the Thirteenth International Conference on Artificial Intelligence and Statistics, JMLR Workshop and Conference Proceedings, 249–256
- Goodwin, S. P. & Whitworth, A. P. 2004, *Astronomy & Astrophysics*, 413, 929
- Greengard, L. 1990, *Computers in Physics*, 4, 142
- Greydanus, S., Dzamba, M., & Yosinski, J. 2019a, CoRR, abs/1906.01563 [1906.01563]
- Greydanus, S., Dzamba, M., & Yosinski, J. 2019b, in *Advances in Neural Information Processing Systems*, Vol. 32 (Curran Associates, Inc.)
- Haber, E. & Ruthotto, L. 2017, *Inverse Problems*, 34, 014004
- Hairer, E., Lubich, C., & Wanner, G. 2006, *Geometric Numerical Integration* (Springer Berlin), 644
- Hambly, B., Xu, R., & Yang, H. 2023, *Mathematical Finance*, 33, 437
- Heggie, D. & Hut, P. 2003, *The Gravitational Million-Body Problem: A Multidisciplinary Approach to Star Cluster Dynamics* (Cambridge University Press, 2003)
- Heggie, D. C. 1975, *Monthly Notices of the Royal Astronomical Society*, 173, 729
- Heggie, D. C. & Mathieu, R. D. 1986, in *The Use of Supercomputers in Stellar Dynamics*, Vol. 267 (Springer), 233–235
- Hénon, M. H. 1971, *apss*, 14, 151
- Horn, P., Saz Ulibarrena, V., Koren, B., & Portegies Zwart, S. 2022, in *ECCOMAS2022*
- Hornik, K. 1991, *Neural Networks*, 4, 251
- Hung, S.-M. & Givigi, S. N. 2016, *IEEE transactions on cybernetics*, 47, 186
- Hut, P., Makino, J., & McMillan, S. 1995, *The Astrophysical Journal Letters*, 443, L93
- Imambi, S., Prakash, K. B., & Kanagachidambaresan, G. 2021, *Programming with TensorFlow: solution for edge computing applications*, 87
- Jänes, J., Pelupessy, I., & Portegies Zwart, S. 2014, *Astronomy & Astrophysics*, 570, A20
- Jia, P., Jia, Q., Jiang, T., & Liu, J. 2023, *The Astronomical Journal*, 165, 233
- Jin, P., Zhang, Z., Zhu, A., Tang, Y., & Karniadakis, G. 2020a, *Neural Networks*, 132, 166
- Jin, P., Zhang, Z., Zhu, A., Tang, Y., & Karniadakis, G. E. 2020b, *Neural Networks*, 132, 166
- Kepler, J. 2015, *Pragae 1609*

- Kingma, D. & Ba, J. 2014, International Conference on Learning Representations
- Kingma, D. & Ba, J. 2015, in 3rd International Conference on Learning Representations, ICLR 2015
- Kiran, B. R., Sobh, I., Talpaert, V., et al. 2022, IEEE Transactions on Intelligent Transportation Systems, 23, 4909
- Kokubo, E. & Ida, S. 2002, The Astrophysical Journal, 581, 666
- Krothapalli, U., Wagner, T., & Kumar, M. 2011, in Infotech@ Aerospace 2011, 1533
- Lalande, F. & Trani, A. 2022, The Astrophysical Journal, 938, 18
- Loh, W.-L. 1996, The Annals of Statistics, 24, 2058
- Lu, L., Meng, X., Mao, Z., & Karniadakis, G. E. 2021, SIAM Review, 63, 208
- Makino, J. 1991, The Astrophysical Journal, 369, 200
- Makino, J. & Aarseth, S. J. 1992, Publications of the Astronomical Society of Japan, 44, 141
- Makino, J., Hut, P., Kaplan, M., & Saygin, H. 2006, New Astronomy, 12, 124
- Mansfield, L. A., Nowack, P. J., Kasoar, M., et al. 2020, npj Climate and Atmospheric Science, 3, 1
- Mignard, F. 1982, Icarus, 49, 347
- Mnih, V., Kavukcuoglu, K., Silver, D., et al. 2015, nature, 518, 529
- Moster, B. P., Naab, T., Lindström, M., & O’Leary, J. A. 2021, Monthly Notices of the Royal Astronomical Society, 507, 2115
- Newton, I. 1687, Newton: Principia Mathematica (Routledge), 97–105
- Newton, I. 1999, The Principia: mathematical principles of natural philosophy (University of California Press)
- Nitadori, K. & Makino, J. 2008, New Astronomy, 13, 498
- Nousiainen, J., Rajani, C., Kasper, M., et al. 2022, Astronomy & Astrophysics, 664, A71
- Novati, G., de Laroussilhe, H. L., & Koumoutsakos, P. 2021, Nature Machine Intelligence, 3, 87
- Paszke, A., Gross, S., Massa, F., et al. 2019, in Advances in Neural Information Processing Systems, Vol. 32 (Curran Associates, Inc.), 8024–8035
- Pedregosa, F., Varoquaux, G., Gramfort, A., et al. 2011, Journal of Machine Learning Research, 12, 2825
- Pelupessy, F. I., Jänes, J., & Portegies Zwart, S. 2012, New Astronomy, 17, 711

- Pham, D. N. 2024, arXiv preprint arXiv:2407.10037
- Plummer, H. C. 1911, *Monthly Notices of the Royal Astronomical Society*, Vol. 71, p. 460-470, 71, 460
- Portegies Zwart, S. & McMillan, S. 2018, *Astrophysical Recipes: the art of AMUSE* (IoP Publishing)
- Portegies Zwart, S. & McMillan, S. 2018, *Astrophysical Recipes; The art of AMUSE*
- Portegies Zwart, S., McMillan, S., Harfst, S., et al. 2009, *New Astronomy*, 14, 369
- Portegies Zwart, S., Pelupessy, I., Martínez-Barbosa, C., van Elteren, A., & McMillan, S. 2020, *Communications in Nonlinear Science and Numerical Simulation*, 85, 105240
- Portegies Zwart, S., Pelupessy, I., Martínez-Barbosa, C., van Elteren, A., & McMillan, S. 2020, *Communications in Nonlinear Science and Numerical Simulation*, 85, 105240
- Portegies Zwart, S. F., McMillan, S. L., van Elteren, A., Pelupessy, F. I., & de Vries, N. 2013, *Computer Physics Communications*, 184, 456
- Raissi, M., Perdikaris, P., & Karniadakis, G. E. 2019a, *Journal of Computational physics*, 378, 686
- Raissi, M., Perdikaris, P., & Karniadakis, G. E. 2019b, *Journal of Computational Physics*, 378, 686
- Rauch, K. P. & Holman, M. 1999, *The Astronomical Journal*, 117, 1087
- Rein, H., Tamayo, D., & Brown, G. 2019, *Monthly Notices of the Royal Astronomical Society*, 489, 4632
- Richardson, D., Michel, P., Walsh, K., & Flynn, K. 2009, *Planetary and Space Science*, 57, 183
- Roa, J., Hamers, A. S., Cai, M. X., & Leigh, N. W. 2020, *Moving Planets Around* (The MIT Press)
- Salpeter, E. E. 1955, *Astrophysical Journal*, vol. 121, p. 161, 121, 161
- Sanz-Serna, J. M. 1992, *Acta Numerica*, 1, 243–286
- Saz Ulibarrena, V., Horn, P., Portegies Zwart, S., et al. 2024, *Journal of Computational Physics*, 496, 112596
- Saz Ulibarrena, V. & Portegies Zwart, S. 2024, Submitted to *Communications in Nonlinear Science and Numerical Simulation*
- Srivastava, N., Kaufman, C., & Müller, G. 1990
- Stone, N. C. & Leigh, N. W. C. 2019, *Nature*, 576, 406
- Sutton, R. S. & Barto, A. G. 2018, *Reinforcement Learning: An Introduction* (MIT press)

- Tamayo, D., Silburt, A., Valencia, D., et al. 2016, *The Astrophysical Journal Letters*, 832, L22
- Telgarsky, M. 2015, <https://arxiv.org/abs/1509.08101> Representation Benefits of Deep Feedforward Networks
- Toomer, G. 1998, *Ptolemy's Almagest* (Princeton University Press)
- Trani, A. A., Leigh, N. W., Boekholt, T. C., & Portegies Zwart, S. 2024, *Astronomy & Astrophysics*, 689, A24
- Tremaine, S. 2015, *The Astrophysical Journal*, 807, 157
- Turaev, D. 2002, *Nonlinearity*, 16, 123
- Verlet, L. 1967, *Physical Review*, 159, 98
- Viquerat, J., Meliga, P., Larcher, A., & Hachem, E. 2022, *Physics of Fluids*, 34
- White, D. B. 2022, in *ASCEND 2022*, 4342
- Wisdom, J. & Holman, M. 1991, *Astronomical Journal* (ISSN 0004-6256), vol. 102, Oct. 1991, p. 1528-1538., 102, 1528
- Xiong, S., Tong, Y., He, X., et al. 2021, in *9th International Conference on Learning Representations, ICLR 2021*
- Yahalom, A. 2022, *Symmetry*, 15, 39
- Yahalom, A. 2024, *Entropy*, 26, 986
- Yatawatta, S. & Avruch, I. M. 2021, *Monthly Notices of the Royal Astronomical Society*, 505, 2141
- Yi, K., Moon, Y.-J., & Jeong, H.-J. 2023, *The Astrophysical Journal Supplement Series*, 265, 34
- Yoshida, H. 1990a, *Physics Letters A*, 150, 262
- Yoshida, H. 1990b, *Physics Letters A*, 150, 262
- Yu, W., Wang, R., Li, R., Gao, J., & Hu, X. 2018, in *2018 IEEE 30th International Conference on Tools with Artificial Intelligence (ICTAI)*, IEEE, 6–11
- Zaghbani, I., Jarray, R., & Bouallègue, S. 2024, in *2024 IEEE 28th International Conference on Intelligent Engineering Systems (INES)*, IEEE, 000245–000250
- Zemp, M., Stadel, J., Moore, B., & Carollo, C. M. 2007, *Monthly Notices of the Royal Astronomical Society*, 376, 273
- Zhu, A., Jin, P., & Tang, Y. 2020, arXiv preprint arXiv:2004.13830