

# References

- [1] M. S. Alnæs, A. Logg, K. B. Ølgaard, M. E. Rognes, and G. N. Wells. Unified Form Language: A domain-specific language for weak formulations of partial differential equations. *ACM Transactions on Mathematical Software*, 40(2), 2014. doi:10.1145/2566630, arXiv:1211.4047.
- [2] Douglas N. Arnold and Anders Logg. Periodic table of the finite elements. *SIAM News*, 2014.
- [3] W. B. Bickford. *A First Course in the Finite Element Method*. Irwin, 2nd edition, 1994.
- [4] D. Braess. *Finite Elements*. Cambridge University Press, Cambridge, third edition, 2007.
- [5] S. C. Brenner and L. R. Scott. *The Mathematical Theory of Finite Element Methods*, volume 15 of *Texts in Applied Mathematics*. Springer, New York, third edition, 2008.
- [6] A. J. Chorin. Numerical solution of the Navier-Stokes equations. *Math. Comp.*, 22:745–762, 1968.
- [7] P. G. Ciarlet. *The Finite Element Method for Elliptic Problems*, volume 40 of *Classics in Applied Mathematics*. SIAM, Philadelphia, PA, 2002. Reprint of the 1978 original [North-Holland, Amsterdam; MR0520174 (58 \#25001)].
- [8] J. Donea and A. Huerta. *Finite Element Methods for Flow Problems*. Wiley Press, 2003.
- [9] K. Eriksson, D. Estep, P. Hansbo, and C. Johnson. *Computational Differential Equations*. Cambridge University Press, 1996.
- [10] A. Ern and J.-L. Guermond. *Theory and Practice of Finite Elements*. Springer, 2004.
- [11] Python Software Foundation. The Python tutorial. <http://docs.python.org/2/tutorial>.
- [12] M. Gockenbach. *Understanding and Implementing the Finite Element Method*. SIAM, 2006.

- [13] K. Goda. A multistep technique with implicit difference schemes for calculating two- or three-dimensional cavity flows. *Journal of Computational Physics*, 30(1):76–95, 1979.
- [14] T. J. R. Hughes. *The Finite Element Method: Linear Static and Dynamic Finite Element Analysis*. Prentice-Hall, 1987.
- [15] J. M. Kinder and P. Nelson. *A Student’s Guide to Python for Physical Modeling*. Princeton University Press, 2015.
- [16] Robert C. Kirby. Fiat, a new paradigm for computing finite element basis functions. *ACM Transactions on Mathematical Software*, 30(4):502–516, 2004.
- [17] Robert C. Kirby and Anders Logg. A compiler for variational forms. *ACM Transactions on Mathematical Software*, 32(3):417–444, 2006.
- [18] J. Kiusalaas. *Numerical Methods in Engineering With Python*. Cambridge University Press, 2005.
- [19] R. H. Landau, M. J. Paez, and C. C. Bordeianu. *Computational Physics: Problem Solving with Python*. Wiley, third edition, 2015.
- [20] H. P. Langtangen. *Python Scripting for Computational Science*. Springer, third edition, 2009.
- [21] H. P. Langtangen. *A Primer on Scientific Programming With Python*. Texts in Computational Science and Engineering. Springer, fifth edition, 2016.
- [22] H. P. Langtangen and L. R. Hellevik. Brief tutorials on scientific Python, 2016. <http://hplgit.github.io/bumpy/doc/web/index.html>.
- [23] H. P. Langtangen and A. Logg. *Solving PDEs in Hours – The FEniCS Tutorial Volume II*. Springer, 2016.
- [24] H. P. Langtangen and K.-A. Mardal. *Introduction to Numerical Methods for Variational Problems*. 2016. <http://hplgit.github.io/fem-book/doc/web/>.
- [25] M. G. Larson and F. Bengzon. *The Finite Element Method: Theory, Implementation, and Applications*. Texts in Computational Science and Engineering. Springer, 2013.
- [26] A. Logg, K.-A. Mardal, and G. N. Wells. *Automated Solution of Partial Differential Equations by the Finite Element Method*. Springer, 2012.
- [27] Anders Logg and Garth N. Wells. DOLFIN: Automated finite element computing. *ACM Transactions on Mathematical Software*, 37(2), 2010.
- [28] M. Pilgrim. *Dive into Python*. Apress, 2004. <http://www.diveintopython.net>.
- [29] A. Quarteroni and A. Valli. *Numerical Approximation of Partial Differential Equations*. Springer Series in Computational Mathematics. Springer, 1994.
- [30] A. Henderson Squillacote. *The ParaView Guide*. Kitware, 2007.
- [31] R. Temam. Sur l’approximation de la solution des équations de Navier-Stokes. *Arc. Ration. Mech. Anal.*, 32:377–385, 1969.

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