GEORGE MASON UNIVERSITY
Department of Mathematical Sciences
4400 University Drive, MS 3F2, Fairfax, Virginia 22030

Math 462 and Math 662, Aug–Oct 2022

Math 463 and Math 663, Oct–Dec 2022

Mathematics of Machine Learning with Industrial Applications – Part I and II

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Goal: The goal of these courses is to create a mathematical understanding of Deep Learning (DL). The DL problems will be cast as constrained optimization problems. These courses will have both theoretical as well as numerical components. Every theoretical aspect will be tested numerically.

In the first part (Math 462 and Math 662), students will develop their own deep learning package. In the second part (Math 463 and Math 663), students will use existing packages such as TensorFlow.

Course description (Math 462 and Math 662):[1] The following topics will be covered (suggested reading: [4, 2, 3, 5, 1]):

- **Week 1:** Introduction to machine learning, Least square regression, Logistic regression and cross entropy, and Regularization.
- **Week 2:** Linear classification using cross entropy
- **Week 3:** Krylov subspace methods: Conjugate gradient method
- **Week 4:** Universal approximation theorem, Activation functions and nonlinear classification models
- **Week 5:** Iterative methods for unconstrained optimization: Gradient descent, Stochastic gradient descent, Line search, Trust-Region methods
- **Week 6:** Single layer neural networks
- **Week 7:** Deep neural networks
- **Week 8:** Stability of DNN and relation to ODEs

Course description (Math 463 and Math 663):[2] The following topics will be covered (suggested reading: [4, 2, 3, 5, 1]):

- **Week 1:** Python
- **Week 2:** Computer Vision
- **Week 3:** Neural Networks and Image Classification
- **Week 4:** Karas & GPUs, Convolutional NNs
- **Week 5:** CNN Architectures
- **Week 6:** CNN Training and Pixel Segmentation
- **Week 7:** ResNets

[1] Notes will be provided

[2] Notes will be provided

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Homework (70%): There will be several HOMEWORKS which will amount to 70% of the final grade. There will be a penalty of 10% per day late; homeworks will not be accepted after one week.

Students are encouraged to work in groups of up to three students but must hand in individual self written proofs and answers.

Exams (30%): There will be a FINAL project and a presentation which will constitute 30% of the final grade.

Certificate of Completion: Center for Mathematics and Artificial Intelligence (CMAI) "Certificate of Completion" will also be provided up on successful completion of courses. The certificate will list the skills learned during the class.

Academic Integrity: GMU is an Honor Code university; please see the Office for Academic Integrity for a full description of the code and the honor committee process. The principle of academic integrity is taken very seriously and violations are treated gravely. What does academic integrity mean in this course? Essentially this: when you are responsible for a task, you will perform that task. When you rely on someone else's work in an aspect of the performance of that task, you will give full credit in the proper, accepted form. Another aspect of academic integrity is the free play of ideas. Vigorous discussion and debate are encouraged in this course, with the firm expectation that all aspects of the class will be conducted with civility and respect for differing ideas, perspectives, and traditions. When in doubt (of any kind) please ask for guidance and clarification.

Mason email accounts. Students must use their MasonLIVE email account for any correspondence during this course. For more information see: `http://masonlive.gmu.edu`.

Office of Disability Services. If you are a student with a disability and you need academic accommodations, please see me and contact the Office of Disability Services (ODS) at 993-2474, `http://ods.gmu.edu`. All academic accommodations must be arranged through the ODS.

University policies The University Catalog, `http://catalog.gmu.edu`, is the central resource for university policies affecting student, faculty, and staff conduct in university academic affairs. Other policies are available at `http://universitypolicy.gmu.edu`. All members of the university community are responsible for knowing and following established policies.

References

[1] Harbir Antil, Drew P. Kouri, Martin-D. Lacasse, and Denis Ridzal, editors. *Frontiers in PDE-constrained optimization*, volume 163 of *The IMA Volumes in Mathematics and its Applications*. Springer, New York, 2018. Papers based on the workshop held at the Institute for Mathematics and its Applications, Minneapolis, MN, June 6–10, 2016.

[2] Yoshua Bengio, Ian Goodfellow, and Aaron Courville. *Deep learning*, volume 1. MIT press Massachusetts, USA:, 2017.

[3] H. C. Elman, D. J. Silvester, and A. J. Wathen. *Finite elements and fast iterative solvers: with applications in incompressible fluid dynamics*. Numerical Mathematics and Scientific Computation. Oxford University Press, New York, 2005.

[4] Guanghui Lan. *First-order and Stochastic Optimization Methods for Machine Learning*. Springer, 2020.

[5] Jorge Nocedal and Stephen J. Wright. *Numerical optimization*. Springer Series in Operations Research and Financial Engineering. Springer, New York, second edition, 2006.