Indian Institute of Space Science and Technology

Thiruvananthapuram

M.Tech. Machine Learning and Computing

Curriculum & Syllabus

(Effective from 2018 Admission)

Department of Mathematics

SEMESTER I

CODE	TITLE	L	T	P	C
MA617	Numerical Linear Algebra	3	0	0	3
MA611	Optimization Techniques	3	0	0	3
MA618	Foundations of Machine Learning	3	0	3	4
MA613	Data Mining	3	0	3	4
E01	*Elective I*	3	0	0	3
MA632	Data Modeling Lab I	0	0	6	2
	Total	**15**	**0**	**12**	**19**

SEMESTER II

CODE	TITLE	L	T	P	C
MA624	Advanced Machine Learning	3	0	3	4
MA625	Statistical Models and Analysis	4	0	0	4
E02	Elective II	3	0	0	3
E03	Elective III	3	0	0	3
E04	Elective IV	3	0	0	3
MA642	Data Modeling Lab II	0	0	6	2
	Total	**16**	**0**	**9**	**19**

SEMESTER III

CODE	TITLE	L	T	P	C
MA851	Seminar	0	0	0	1
MA852	Project Work – Phase I	0	0	0	14
	Total	**0**	**0**	**0**	**15**

SEMESTER IV

CODE	TITLE	L	T	P	C
MA853	Project Work – Phase II	0	0	0	17

LIST OF ELECTIVES FOR SEMESTER I

CODE	TITLE
MA869	Discrete Mathematics and Graph Theory
	Introduction to Internet of Things ★
	Introduction to Parallel Programming ★
AVD614	Image and Video Processing *

★ Online courses from SWAYAM

LIST OF ELECTIVES FOR SEMESTER II

CODE	TITLE
MA871	Advanced Kernel Methods
MA872	Advanced Optimization
AVD864	Computer Vision *
MA873	Graphical and Deep Learning Models
MA867	Reinforcement Learning
MA874	Theory of Algorithms
MA875	Topological Data Analysis
	Cloud Computing★

★ Online course from SWAYAM

SEMESTER–WISE CREDITS

Semester	I	II	III	IV	Total
Credits	19	19	15	17	70

SEMESTER I

Numerical Linear Algebra 3 credits

Introduction to fundamental linear algebra problems and their importance, computational difficulties using theoretical linear algebra techniques, review of core linear algebra concepts; introduction to matrix calculus; floating point representation; conditioning of problems and stability of algorithms; singular value decomposition and regularization theory.

References:

1. Datta, B. N., *Numerical Linear Algebra and Applications*, 2nd Ed., Siam (2010).
2. Demmel, J. W., *Applied Numerical Linear Algebra*, Siam (1997).
3. Lu, S. and Pereversev, S., *Regularization Theory for Ill-posed Problems: Selected Topics'* Walter de Gruyter GmbH, Berlin/Boston, Inverse and Ill-Posed Problems Series 58.

Optimization Techniques 3 credits

Optimization: need for unconstrained methods in solving constrained problems, necessary conditions of unconstrained optimization, structure methods, quadratic models, methods of line search, steepest descent method; quasi-Newton methods: DFP, BFGS, conjugate-direction methods: methods for sums of squares and nonlinear equations; linear programming: sim- plex methods, duality in linear programming, transportation problem; nonlinear programming: Lagrange multiplier, KKT conditions, convex programing.

References:

1. Chong, E. K. and Zak, S. H., *An Introduction to Optimization*, 2nd Ed., Wiley India (2001).
2. Luenberger, D. G. and Ye, Y., *Linear and Nonlinear Programming*, 3rd Ed., Springer (2008).
3. Kambo, N. S., *Mathematical Programming Techniques*, East-West Press (1997).

Foundations of Machine Learning 4 credits

Machine learning basics: capacity, overfitting and underfitting, hyperparameters and validation sets, bias & variance; PAC model; Rademacher complexity; growth function; VC-dimension; fundamental concepts of artificial neural networks; single layer perceptron classifier; multi-layer feed forward networks; single layer feed-back networks; associative memories; introductory concepts of reinforcement learning, Markhov decision process.

References:

1. Mohri, M., Rostamizadedh, A., and Talwalkar, A., *Foundations of Machine Learning*, The MIT Press (2012).
2. Jordon, M. I. and Mitchell, T. M., *Machine Learning: Trends, perspectives, and prospects*, Vol. 349, Issue 6245, pp. 255-260, Science 2015.
3. Shawe-Taylor, J. and Cristianini, N., *Kernel Methods for Pattern Analysis*, Cambridge Univ. Press (2004).
4. Haykin, S., *Neural Networks: A Comprehensive Foundation*, 2nd ed., Prentice Hall (1998).
5. Hassoun, M. H., *Fundamentals of Artificial Neural Networks*, PHI Learning (2010).
6. Ripley, B. D., *Pattern Recognition and Neural Networks*, Cambridge Univ. Press (2008).
7. Sutton R. S. and Barto, A. G., *Reinforcement Learning: An Introduction*, The MIT Press (2017).

Data Mining **4 credits**

Introduction to data mining concepts; linear methods for regression; classification methods: k-nearest neighbour classifiers, decision tree, logistic regression, naive Bayes, Gaussian discrim- inant analysis; model evaluation & selection; unsupervised learning: association rules; apriori algorithm, FP tree, cluster analysis, self organizing maps, google page ranking; dimensional- ity reduction methods: supervised feature selection, principal component analysis; ensemble learning: bagging, boosting, AdaBoost; outlier mining; imbalance problem; multi class classi- fication; evolutionary computation; introduction to semi supervised learning, transfer learning, active learning, data warehousing.

References:

1. Bishop, C. M., *Pattern Recognition and Machine Learning*, Springer (2006).
2. Hastie, T., Tibshirani, R., and Friedman, J., *The Elements of Statistical Learning: Data Mining, Inference, and Prediction*, Springer (2002).
3. Han, J., Kamber, M., and Pei, J., *Data Mining: Concepts and Techniques*, 3rd ed., Morgan Kaufmann (2012).
4. Mitchell, T. M., *Machine Learning*, McGraw-Hill (1997).

Elective I **3 credits**

Data Modeling Lab I **2 credits**

Programming with Python: Introduction to Python, data types, file operations, object oriented programming.

Programming with R: Introduction to R, string operations, data visualization.

SEMESTER II

Advanced Machine Learning **4 credits**

Kernel Methods: reproducing kernel Hilbert space concepts, kernel algorithms, multiple kernels, graph kernels; multitasking, deep learning architectures; spectral clustering ; model based clustering, independent component analysis; sequential data: Hidden Markhov models; factor analysis; graphical models; reinforcement learning; Gaussian processes; motiff discovery; graph-based semisupervised learning; natural language processing algorithms.

References:

1. Bishop, C. M., *Pattern Recognition and Machine Learning*, Springer (2006).
2. Hastie, T., Tibshirani, R., and Friedman, J., *The Elements of Statistical Learning: Data Mining, Inference, and Prediction*, Springer (2002).
3. Cristianini, N. and Shawe-Taylor, J., *An Introduction to Support Vector Machines and other kernel-based methods*, Cambridge Univ. Press (2000).
4. Scholkopf, B. and Smola, A. J., *Learning with Kernels: Support Vector Machines, Regularization, Optimization, and Beyond*, The MIT Press (2001).
5. Sutton R. S. and Barto, A. G., *Reinforcement Learning: An Introduction*, The MIT Press (2017).
6. Goodfellow, I., Bengio, Y., and Courville, A., *Deep Learning*, The MIT Press (2016).
7. Koller D. and Friedman, N., *Probabilistic Graphical Models: Principles and Techniques*, The MIT Press (2009).

Statistical Models and Analysis **4 credits**

An overview of basic probability theory and theory of estimation; Bayesian statistics; maximum a posteriori (MAP) estimation; conjugate priors; Exponential family; posterior asymptotics; linear statistical models; multiple linear regression: inference technique for the general linear model, generalised linear models: inference procedures, special case of generalised linear models leading to logistic regression and log linear models; introduction to non-linear modelling; sampling methods: basic sampling algorithms, rejection sampling, adaptive rejection sampling, sampling and the EM algorithm, Markhov chain, Monte Carlo, Gibbs sampling, slice sampling.

References:

1. Dobson, A. J. and Barnett, A. G., *An Introduction to Generalised Linear Models*, 3rd ed., Chapman and Hall/CRC (2008).
2. Krzanowski, W. J., *An Introduction to Statistical Modeling*, Wiley (2010).
3. Hastie, T., Tibshirani, R., and Friedman, J., *The Elements of Statistical Learning: Data Mining, Inference, and Prediction*, Springer (2002).
4. Bishop, C. M., *Pattern Recognition and Machine Learning*, Springer (2006).

Elective II **3 credits**

Elective III **3 credits**

Elective IV **3 credits**

Data Modeling Lab II **2 credits**

Big data analytics: Introduction to spark 2.0 & tensor flow, tools to assess the quality of big data analytics.

Mini project on a topic related with data modeling.

SEMESTER III

Seminar 1 credit

Project Work – Phase I 14 credits

SEMESTER IV

Project Work – Phase II 17 credits

ELECTIVES FOR SEMESTER - I

Discrete Mathematics and Graph Theory 3 credits

Basic counting principle: Pigeonhole principle, inclusion - exclusion principle, recurrence relations, generating functions. Fundamentals of logic, set theory, language, and finite state machines.

Undirected and direct graphs, modelling with graphs, trial and cycle- Eulerian trial and Hamilton cycle, connectivity and trees. Graph algorithms: BFS, DFS, shortest path, optimal spanning trees, matching, job assignment problem, optimal transportation through flows in networks.

References:

1. Liu, C. L., *Elements of Discrete Mathematics*, 2nd Ed., Tata McGraw-Hill (2000).
2. Grivaldi, R. P. and Ramana, B. V., *Discrete and Combinatorial mathematics*, Pearson (2008).
3. Graham, R. L., Knuth, D. E., and Patashnik, O., *Concrete Mathematics*, 2nd Ed., Addison-Wesley (1994).
4. Rosen, K. H., *Discrete Mathematics and its Applications*, 6th Ed., Tata McGraw-Hill (2007).

Image and Video Processing 3 Credits

Human visual system and image perception; monochrome and colour vision models; image digitization, display and storage; 2 - D signals and systems; image transforms - 2D DFT, DCT, KLT, Harr transform and discrete wavelet transform; image enhancement: histogram processing, spatial - filtering, frequency - domain filtering; image restoration: linear degradation model, inverse filtering, Wiener filtering; image compression: lossy and lossless compression, image compression standards, image analysis: edge and line detection, segmentation, feature extraction, classification; image texture analysis; morphological image processing: binary morphology - erosion, dilation, opening and closing operations, applications; basic gray - scale morphology operations; colour image processing: colour models and colour image processing Fundamentals of digital video processing - Coverage includes spatio - temporal sampling, motion analysis, parametric motion models, motion - compensated filtering, and video processing operations.

References

1. Fundamentals of Digital Image processing, A. K. Jain, Pearson Education, 1989
2. Digital Image Processing, R. C. Gonzalez and R. E. Woods: Pearson Education, 2001
3. Digital Image Processing using MATLAB, R. C. Gonzalez , R. E. Woods and S. L. Eddins: Pearson Education, 2004.
4. Digital Image Processing; G. A. Baxes: John Wiley, 1994
5. Digital Image Processing and Computer Vision; R.J. Schalkoff: John Wiley, 1989.
6. Image Processing; Sid Ahmed: McGraw - Hill, 1994.
7. Digital Video and Audio Compression; S.J. Solari: McGraw - Hill, 1996.
8. Video Processing and Communications" by Yao Wang, Joern Ostermann, and Ya - Qin Zhang, Prentice Hall, 2002, ISBN 0 - 13 - 017547 - 1
9. Digital Video Processing , M. Tekalp Prentice Hall, 1995, ISBN 0 - 13 - 190075 - 7
10. The Art of Digital Video, J. Watkinson, 3rd edition, Focal Press, 2000. 11. "Video Demystified", K. Jack, 3rd edition, Llh Technology Publishing, 2001.
11. Motion Analysis and Image Sequence Processing, edited by M.I. Sezan and R.L. Lagendijk, Kluwer Academic Publishers, 1993.
12. Image and Video Compression Standards: Algorithms and Architectures, V. Bhaskaran and K. Konstantinides, Kluwer Academic Publishers, 2nd edition, 1997.

Introduction to Internet of Things **3 credits**

Online Swayam course

Introduction to Parallel Programming **3 credits**

Online Swayam course

ELECTIVES FOR SEMESTER – II

Advanced Kernel Methods **3 credits**

Theory of reproducing kernel Hilbert space, support vector machines, kernel ridge regression, kernel feature extraction, kernel online learning, Bayesian kernel methods, graph kernels, kernels for text, kernels for structured data.

References:

1. Bishop, C. M., *Pattern Recognition and Machine Learning*, Springer (2006).
2. Cristianini, N. and Shawe-Taylor, J., *An Introduction to Support Vector Machines and other kernel-based methods*, Cambridge Univ. Press (2000).
3. Scholkopf, B. and Smola, A. J., *Learning with Kernels: Support Vector Machines, Regularization, Optimization, and Beyond*, The MIT Press (2001).
4. Shawe-Taylor, J. and Cristianini, N., *Kernel Methods for Pattern Analysis*, Cambridge Univ. Press (2004).

Advanced Optimization **3 credits**

Unconstrained Optimization: line search method: Wolf condition, Goldstein condition, sufficient decrease and backtracking, Newtons method and Quazi Newton method; trust region method: the Cauchy point, algorithm based on Cauchy point, improving on the Cauchy point, the Dog-leg method, two-dimensional subspace reduction; nonlinear conjugate gradient method: the Fletcher Reeves method.

Constrained Optimization: penalty method, quadratic penalty method, convergence, non smooth penalty function, L_1 penalty method, augmented Lagrangian method; quadratic programming, Schur complementary, null space method, active set method for convex QP; sequential quadratic programming, convex programming.

References:

1. Boyd, S. and Vandenberghe, L., *Convex Optimization*, Cambridge Univ. Press (2004).
2. Nocedel, J. and Wright, S. *Numerical Optimization*, Springer (2006).

Computer Vision **3 Credits**

Image Formation Models, Monocular imaging system, Orthographic & Perspective Projection , Camera model and Camera calibration , Binocular imaging systems Image Processing and Feature Extraction , Image representations (continuous and discrete), Edge detection, Motion Estimation , Regularization theory, Optical computation , Stereo Vision , Motion estimation , Structure from motion Shape Representation and Segmentation , Deformable curves and surfaces , Snakes and active contours , Level set representations , Fourier and wavelet descriptors

• Medial representations , Multiresolution analysis Object recognition , Hough transforms and other simple object recognition methods , Shape correspondence and shape matching , Principal component analysis, Shape priors for recognition

References

1. Computer Vision - A modern approach, D. Forsyth and J. Ponce, Prentice Hall ,2002
2. Introductory Techniques for 3D Computer Vision, by E. Trucco and A. Verri, Publisher: Prentice Hall,1998.
3. Robot Vision, by B. K. P. Horn, McGraw - Hill,1986.

Graphical and Deep Learning Models **3 credits**

Graphical Models: Basic graph concepts; Bayesian Networks; conditional independence; Markov Networks; Inference: variable elimination, belief propagation, max-product, junction trees, loopy belief propogation, expectation propogation, sampling; structure learning; learning with missing data.

Deep Learning: recurrent networks; probabilistic neural nets; Boltzmann machines; RBMs; sigmoid belief nets; CNN; autoencoders; deep reinforcement learning; generative adversarial networks; structured deep learning; applications.

References:

1. Koller D. and Friedman, N., *Probabilistic Graphical Models: Principles and Techniques*, The MIT Press (2009).
2. Barber, D., *Bayesian Reasoning and Machine Learning*, Cambridge Univ. Press (2012).

3. Bishop, C. M., *Pattern Recognition and Machine Learning*, Springer (2006).
4. Hastie, T., Tibshirani, R., and Friedman, J., *The Elements of Statistical Learning: Data Mining, Inference, and Prediction*, Springer (2002).
5. Murphy, K. P., *Machine Learning: A Probabilistic Perspective*, The MIT Press (2012).
6. Goodfellow, I., Bengio, Y., and Courville, A., *Deep Learning*, The MIT Press (2016).

Reinforcement Learning — 3 credits

The reinforcement learning problem; tabular & approximate solution methods: dynamic programming, Monto-Carlo Methods, temporal difference learning, eligibility traces; planning and learning; dimensions of reinforcement learning.

References:

1. Sutton R. S. and Barto, A. G., *Reinforcement Learning: An Introduction*, The MIT Press (2017).
2. Tesauro G., *Temporal Difference Learning and TD-Gammon*, Communications of the Association for Computing Machinery (1995).

Theory of Algorithms — 3 credits

Greedy and dynamic programming algorithms; Kruskals algorithm for minimum spanning trees; the folklore algorithm for the longest common subsequence of two strings; Dijstras algorithm and other algorithms for the shortest path problem; divide-and-conqueror and checkpoint algorithms; the Hirshbergs algorithm for aligning sequences in linear space; quick sorting; the Knuth-Morrison-Pratt algorithm; suffix trees; data structures: chained lists, reference lists, hash- ing; the Chomsky-hierarchy of grammars; parsing algorithms; connections to the automaton theory; Turing-machines; complexity and intractability; complexity of algorithms; the complex- ity classes P and NP. 3-satisfiability, and NP-complete problems; stochastic Turing machines; the complexity class BPP; counting problems; #P, #P-complete; FPRAS; discrete time Markov chains; reversible Markov chains; Frobenius theorem; relationship between the second largest eigenvalue modulus and convergence of Markov chains; upper and lower bounds on the second largest eigenvalue; the Sinclair-Jerrum theorem: relationship between approximate counting and sampling.

References:

1. Dasgupta, S. S., Papadimitriou, C. H., Vazirani, U. V., *Algorithms*, McGraw-Hill Higher Education (2006).
2. Kleinberg , J. and Tardos, E., *Algorithm Design*, Addison-Wesley (2006).

3. Cormen, T. H., Leiserson, C. E., Rivest, R. L., and Stein, C., *Introduction to Algorithms*, 3rd Ed., The MIT Press (2009).

Topological Data Analysis **3 credits**

Basics of Topology; complexes on data; homology; topological Persistence; computing Betti numbers; reconstruction from data; topology inference from data; computing optimized homology cycles; reeb graphs from data; topology of Laplace operators, spectra approximation.

References:

1. Edelsbrunner, H. and Harer, J. L., Computational Topology, American Mathematical Soci- ety (2010).
2. Dey, T. K., Curve and Surface Reconstruction: Algorithms with Mathematical Analysis, Cambridge Univ. Press (2011).
3. Hatcher, A., Algebraic Topology, Cambridge Univ. Press (2001).

Cloud Computing **3 credits**

Online Swayam course

- **The two elective courses AVD614 and AVD864 are from the Avionics Department.**