**BIRLA INSTITUTE OF TECHNOLOGY & SCIENCE, PILANI**

**WORK INTEGRATED LEARNING PROGRAMMES**

**Digital**

Part A: Content Design

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| --- | --- |
| **Course Title** | Advanced Deep Leaning |
| **Course No(s)** | ZG513 |
| **Credit Units** | 4 |
| **Credit Model** | 1 - 0.5 - 1.5  1 unit for class room hours, 0.5 unit for Tutorial, 1.5 units for  Student preparation.  1 unit = 32 hours |
| **Content Authors** | Dr. Sugata Ghosal |
| **Version** | 1.0 |
| **Date** | Nov 24th, 2024 |

Course Description

This course will cover two areas of deep learning in which labeled data is not required: Deep Generative Models and Self-supervised Learning. Recent advances in generative models have made it possible to realistically model high-dimensional raw data such as natural images, audio waveforms and text corpora. Strides in self-supervised learning have started to close the gap between supervised representation learning and unsupervised representation learning in terms of fine-tuning to unseen tasks. This course will cover the theoretical foundations of these topics as well as their newly enabled applications.

Topics:

Introduction to Representation Learning, PCA and variants, likelihood based models, flow models, autoregressive models, latent variables, Deep autoencoders, Boltzmann Machines, Generative Adversarial learning, Variants of GAN and applications, DeepDream, neural style transfer, self-supervised learning, semi-supervised learning, language model learning, applications in time series modelling

**Course Objectives**

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| --- | --- |
| **No** | Topics |
| **CO1** | Learn about foundational principles of unsupervised deep learning |
| **CO2** | Learn about semi-supervised and self-supervised deep learning |
| **CO3** | Learn about representation learning |
| **CO4** | Learn about generative modelling and applications |

**Text Book(s)**

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| --- | --- |
| T1 | [Understanding Deep Learning](https://udlbook.github.io/udlbook/), The MIT Press., 2023, Simon J.D. Prince |
| T2 | Deep Learning (Adaptive Computation and Machine Learning series) Hardcover – 18 November 2016, Aaron Courville, Ian Goodfellow, Yoshua Bengio |

**Reference Book(s) & other resources**

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| --- | --- |
| R1 | Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow: Concepts, Tools, and Techniques to Build Intelligent Systems, Aurélien Géron |
| R2 | Deep Learning with Python, François Chollet |
| R3 | Research Papers, Blogs |

Module 1. Introduction

* 1. Unsupervised, semi-supervised, self-supervised learning
  2. Representation learning
  3. Generative Modeling

Module 2. PCA variants

2.1 Randomized PCA

2.2 Incremental PCA

2.3 Kernel PCA

2.3 Probabilistic PCA

2.5 Sparse PCA

2.6 Canonical Correlation Analysis (CCA)

2.6 Locally Linear Embedding (LLE)

2.6 Independent Component Analysis

2.7 Factor Analysis

2.8 Manifold learning

Module 3. Autoencoders

3.1 Type of activation and loss functions

3.2 Undercomplete Vs. Overcomplete autoencoders

3.3 Relationship with PCA

3.4 Regularization

3.4.1 Denoising autoencoder

3.4.2 Sparse autoencoder

3.4.3 Contractive Autoencoders

5.5 Effect of Depth

5.6 Application of Autoencoders

Module 4. Autoregressive Models

4.1 Motivation

4.2 Simple generative models: histograms

4.3 Parameterized distributions and maximum likelihood

4.4 Autoregressive Models

4.4.1 Recurrent Neural Nets

4.4.2 Masking-based Models

Masked AEs for Distribution Estimation (MADE)

Masked Convolutions

WaveNet

PixelCNN and Variants

Applications in super-resolution, colorization

Speed Up Strategies

Module 5. Normalizing Flow Models

* 1. Difference with AR Models
  2. Foundations of 1-D Flow
  3. 2-D Flow
  4. N-dimensional flows
     1. AR and inverse AR flows
     2. NICE/ RealNVP
     3. Glow, Flow++
  5. Dequantization
  6. Applications in super-resolution, text/audio synthesis, point cloud generation

Module 6. Variational Inteferencing

6.1 Latent Variable Models

6.2 Training Latent Variable Models

6.2.1 Exact Likelihood

6.2.2 Sampling; Prior, Importance

6.2.3 Importance Weighted AE

Variational/Evidence Lower Bound

Optimizing VLB/ELBO

VAE Variants: VQ-VAE, AR\_VAE, Beta VAE

Variational Dequantization

Module 7. Generative Adversarial Network

7.1 Variants

7.1.1 Cycle GAN

7.1.2. DCGan

7.1.3. Style GAN

7.2. Applications of GAN

Module 8. Semi-supervised and Self-Supervised Learning

8.1 In-painting, colorization

8.3 proxy tasks in computer vision

8.3.1 relative patch prediction

8.3.2. jigjaw puzzles, rotations,

8.3.3. contrastive learning

Module 9. Language Modeling

9.1 Motivation and Intro,

9.2 Introduction to Language Models

9.3 A digression into Transformer, Word2Vec, BERT, ….., GPT

Module 10. Time Series Modeling and Generation

10.1 Advanced VAE and GAN techniques for modelling of time-series data

10.2 Generation of time-series data (ARIMA, S-ARIMA etc.)

**Learning Outcomes:**

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| No | Learning Outcomes |
| LO1 | A strong understanding of the foundations of deep unsupervised learning |
| LO2 | Able to solve problems using appropriate unsupervised learning techniques |
| LO3 | A strong understanding of the foundations of generative modeling |

**Part B: Learning Plan**

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| --- | --- |
| **Academic Term** | 2023-24 Semester 1 |
| **Course Title** | Advanced Deep Learning |
| **Course No** | ZG 513 |
| **Lead Instructor** | Dr. Sugata Ghosal |

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| Session No. | Topic Title | Study/HW Resource Reference |
| 1 | **Introduction**  Unsupervised, semi-supervised, self-supervised learning ; Representation learning; Refresher of supervised deep learning |  |
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| 2 | **PCA and Variants**  2.1 Randomized PCA  2.2 Incremental PCA  2.3 Kernel PCA  2.3 Probabilistic PCA  2.5 Sparse PCA  2.6 Canonical Correlation Analysis (CCA)  2.6 Locally Linear Embedding (LLE)  2.6 Independent Component Analysis  2.7 Factor Analysis  2.8 Manifold learning |  |
| 3 | Autoencoders  3.1 Type of activation and loss functions  3.2 Undercomplete Vs. Overcomplete autoencoders  3.3 Relationship with PCA |  |
| 4 | Autoencoders (contd)  3.4 Regularization  3.4.1 Denoising autoencoder  3.4.2 Sparse autoencoder  3.4.3 Contractive Autoencoders  3.5 Effect of Depth  3.6 Application of Autoencoders |  |
| 5 | Autoregressive Models  4.1 Motivation  4.2 Simple generative models: histograms  4.3 Parameterized distributions and maximum likelihood  4.4 Autoregressive Models  4.4.1 Recurrent Neural Nets  4.4.2 Masking-based Models  Masked AEs for Distribution Estimation (MADE)  Masked Convolutions  WaveNet  PixelCNN and Variants  Applications in super-resolution, colorization |  |
| 6 | Normalizing Flow Models   * 1. Difference with AR Models   2. Foundations of 1-D Flow   3. 2-D Flow   4. N-dimensional flows      1. AR and inverse AR flows      2. NICE/ RealNVP      3. Glow, Flow++   5. Dequantization   6. Applications in super-resolution, text/audio synthesis, point cloud generation |  |
| 7 | Variational Inferencing (1)  6.1 Latent Variable Models  6.2 Training Latent Variable Models  6.2.1 Exact Likelihood  6.2.2 Sampling; Prior, Importance  6.2.3 Importance Weighted AE  Variational/Evidence Lower Bound  Optimizing VLB/ELBO  VAE Variants: VQ-VAE, AR\_VAE, Beta VAE  Variational Dequantization |  |
| 8 | Review of Session 1 to 7 | Books, Web references and Slides |
| 9 | Generative Adversarial Networks  Principles, minimax optimization, DCGAN |  |
| 10 | Other variants of Generative Adversarial Networks  Cycle GAN, Style GAN, Applications of GAN |  |
| 11 | Semi-supervised and Self-Supervised Learning  In-painting, colorization, split-brain autoencoder, proxy tasks in computer vision: relative patch prediction, jigjaw puzzles, rotations, contrastive learning: |  |
| 12 | Semi-supervised and Self-Supervised Learning (Contd)  word2vec, contrastive predictive coding, instance discrimination, current instance discrimination models |  |
| 13 | Language Modeling  Motivation and Intro, Introduction to Language Models, History of Neural Language Models, A digression into Transformer |  |
| 14 | Language Modeling (Contd)  Word2Vec, BERT, ….., GPT |  |
| 15 | Time Series Modeling and Generation  Advanced VAE and GAN techniques for modelling and generation of time-series data (ARIMA, S-ARIMA etc.) |  |
| 16 | Review of session 9 to 15 | Books, Web references and Slides |

**Detailed Plan for Lab work**

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| --- | --- | --- | --- |
| **Lab No.** | **Lab Objective** | **Lab Sheet Access URL** | **Session Reference** |
| 1 | Autoencoders |  |  |
| 2 | Deep Autoencoders |  |  |
| 3 | Convolutional Autoencoders |  |  |
| 4 | Variational Autoencoders |  |  |
| 5 | Generative Adversarial Networks |  |  |

**Evaluation Scheme**:

Legend: EC = Evaluation Component; AN = After Noon Session; FN = Fore Noon Session

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| --- | --- | --- | --- | --- | --- |
| No | Name | Type | Duration | Weight | Day, Date, Session, Time |
| EC-1 | Quiz – Best 2 out of 3 (or Best 1 out of 2) | Online | ~1 hour | 10% |  |
|  | Assignment-I | Take Home | ~2-3 weeks | 10% |  |
|  | Assignment-II | Take Home | ~2-3 weeks | 10% |  |
| EC-2 | Mid-Semester Test | Closed Book |  | 30% |  |
| EC-3 | Comprehensive Exam | Open Book |  | 40% |  |

**Note:**

Syllabus for Mid-Semester Test (Open Book): Topics in Session Nos. 1 to 8

Syllabus for Comprehensive Exam (Open Book): All topics (Session Nos. 1 to 16)

**Important links and information:**

Elearn portal: <https://elearn.bits-pilani.ac.in> or Canvas

Students are expected to visit the Elearn portal on a regular basis and stay up to date with the latest announcements and deadlines.

Contact sessions: Students should attend the online lectures as per the schedule provided on the Elearn portal.

Evaluation Guidelines:

1. EC-1 consists of either two Assignments or three Quizzes. Students will attempt them through the course pages on the Elearn portal. Announcements will be made on the portal, in a timely manner.
2. For Closed Book tests: No books or reference material of any kind will be permitted.
3. For Open Book exams: Use of books and any printed / written reference material (filed or bound) is permitted. However, loose sheets of paper will not be allowed. Use of calculators is permitted in all exams. Laptops/Mobiles of any kind are not allowed. Exchange of any material is not allowed.
4. If a student is unable to appear for the Regular Test/Exam due to genuine exigencies, the student should follow the procedure to apply for the Make-Up Test/Exam which will be made available on the Elearn portal. The Make-Up Test/Exam will be conducted only at selected exam centres on the dates to be announced later.

It shall be the responsibility of the individual student to be regular in maintaining the self study schedule as given in the course handout, attend the online lectures, and take all the prescribed evaluation components such as Assignment/Quiz, Mid-Semester Test and Comprehensive Exam according to the evaluation scheme provided in the handout.