*Course Structures & Syllabi for*

***Doctor of Philosophy (Ph.D.)***

Department of Computer Science Institute of Science
Banaras Hindu University

***(Applicable for the students admitted w.e.f. academic session 2022-23)***

# *Doctor of Philosophy (Ph.D.) Coursework*

*Semester-wise Distribution of Courses and Credits*

| ***SEMESTER I*** | | |
|---|---|---|
| **Course Code** | **Course Title** | **Credits** |
| CS210 | Advanced Course in Data Structures and Algorithms | 04 |
| CS3XX | Major Elective I | 04 |
| CS3XX | Major Elective II | 04 |
| | **Total** | **12** |

| ***SEMESTER II*** | | |
|---|---|---|
| **Course Code** | **Course Title** | **Credits** |
| CS411 | Computational Tools & Techniques | 04 |
| | **Total** | **04** |
| | **Grand Total** | **16** |

## List of Major Elective Courses:

| **Course Code** | **Course Title** | **Credits** |
|---|---|---|
| **Basket 1: Data Science** | | |
| CS311 | Data Mining | 04 |
| CS312 | Information Retrieval | 04 |
| CS313 | Text Mining | 04 |
| CS314 | Quantitative Science Studies | 04 |
| CS315 | Statistical Learning | 04 |
| CS316 | Big Data Analytics | 04 |
| **Basket 2: Artificial Intelligence & Machine Learning** | | |
| CS321 | Artificial Neural Networks | 04 |
| CS322 | Deep Learning | 04 |
| CS323 | Human Computer Interaction | 04 |
| CS324 | Heuristics & Metaheuristics | 04 |
| CS325 | Fuzzy Logic and Applications | 04 |
| **Basket 3: Network Technologies and Applications** | | |
| CS331 | Wireless Sensor Networks | 04 |
| CS332 | Mobile Adhoc Networks | 04 |
| CS333 | Software Defined Networks | 04 |
| CS334 | Network Security | 04 |
| CS335 | Distributed Systems | 04 |
| **Basket 4: Signal, Speech and Image Processing** | | |
| CS341 | Image Processing | 04 |
| CS342 | Image Analysis and Computer Vision | 04 |
| CS343 | Compressive Sensing and Applications | 04 |
| CS344 | Digital Signal Processing, Sensors and Systems | 04 |
| CS345 | Speech Processing and Recognition | 04 |
| CS346 | Statistical Pattern Recognition | 04 |
| **Basket 5: Cloud Computing and IoT** | | |
| CS351 | Parallel Computing | 04 |
| CS352 | Cloud Computing | 04 |

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| CS353 | Internet of Things | 04 |
| CS354 | Embedded Systems | 04 |
| CS355 | Blockchain Technologies | 04 |

| CS210 | Advanced Course in Data Structures and Algorithms | L | T | P |
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**Advanced Data Structures**: Binary Search Trees, Red-Black Trees, B-Trees, Binomial Heaps, Fibonacci Heaps, Data Structures for Disjoint Sets, Topological sorting; Matching, Network Flows; Bipartite graphs.

**Approximation Algorithms**: Approximate solutions to Vertex cover problem, Set covering problem, traveling-salesman problem, subset-sum problem.

**Probabilistic and Randomization Algorithms**: Solving Hiring problem, Indicator random variables, randomized algorithms.

**Multithreaded algorithms**: basics, multithreaded matrix multiplication, multi-threaded merge sort.

**Matrix Operations**: Solving system of linear equations, Inverting Matrices; Polynomials and FFT, Efficient implementation of FFT, Number theoretic algorithms (GCD, modulo arithmetic, Chinese remainder theorem), string matching algorithms (Rabin Karp algorithm, string matching with Finite State Automata, KMP (Knuth-Morris-Pratt) algorithm, Boyer-Moore algorithm)

**Computational complexity**: Problem classes: P, NP, NP-complete, NP-hard, Reduction, Cook's theorem, NP-complete Problems, Sequencing Problem, Partitioning Problem, Graph Coloring.

***Suggested Readings:***


1. T. H. Cormen, C. E. Leiserson, R. L. Rivest, C. Stein, Introduction to Algorithms, PHI.
2. M. A. Weiss, Data Structures and Problem Solving Using Java, Addison Wesley.
3. A. Aho, V. Alfred, J. Hopcroft, J. D. Ullman, The Design and Analysis of Computer Algorithms, Addison Wesley.
4. J. Kleinberg, E. Tardos, Algorithm Design, Pearson.
5. D. E. Knuth, The Art of Computer Programming, Pearson.


| CS311 | Data Mining | L | T | P |
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**Introduction**: The idea of Data Mining, Data Mining Functionalities, Association Analysis, Classification and Prediction, Cluster Analysis, Outlier Analysis, Major issues in Data Mining, KDD process, Difference between Data Mining, Data Warehouse, OLAP and DBMS.

**Data Preprocessing**: Data cleaning, Data Integration and Transformation, Data Reduction. Architectures of Data Mining Systems.

**Mining Association Rules in Large Databases**: Association Rule Mining, Mining Single-Dimensional Boolean Association Rules from Transactional Database, Mining multilevel association rules from transaction databases, constraint based association mining.

**Classification, Prediction and Cluster Analysis**: Issues, Classification by Decision Tree induction, Prediction, Cluster Analysis- types of data in cluster analysis, Partitioning.

**Mining complex Types of Data:** Spatial Databases, Multimedia Databases, Time-series and sequence data, Text databases, WWW.

**Applications and Trends in Data Mining**: Application, Social Impacts.

### *Suggested Readings:*


1. J. Han and M. Kamber, "Data Mining: Concepts and Techniques", Academic Press.
2. I. H. Witten et al., Data Mining: Practical machine Learning Tools and Techniques, Morgan Kaufmann Publisher.
3. A. Rajaraman and J. Ullman, Mining of massive datasets, CUP.


| CS312 | Information Retrieval | L | T | P |
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**Introduction:** Information, Information Need and Relevance; The IR System; Early developments in IR, User Interfaces.

**Retrieval Evaluation:** Notion of Precision and Recall; Precision-Recall Curve, Standard Performance Measures such as MAP, Reciprocal ranks, F-measure, NDCG, Rank Correlation, Standard Data sets.

**Retrieval and IR Models:** Boolean Retrieval; Term Vocabulary and Postings list; Ranked retrieval; Inverted Index, Index Construction; Index compression.

**Document Processing:** Representation; Vector Space Model; Feature Selection; Stop Words; Stemming; Notion of Document Similarity.

**Link Analysis**: Page Rank, HITs, Web Crawling.

Applications.

### *Suggested Readings:*


1. R. Baeza-Yaets, B. Ribeiro-Neto, Modern Information Retrieval: The Concept and Technology behind Search, 2nd Edition, Addison-Wesley.
2. C. D. Manning, P. Raghvan, H. Schutze, Introduction to Information Retrieval, Cambridge University Press.
3. D. A. Grossman, O. Frieder, Information Retrieval: Algorithms and Heuristics, 2nd Ed., Springer.
4. S. Buettcher, Charles L.A. Clarke, G. V. Carmack, Information Retrieval: Implementing and Evaluating Search Engines, MIT Press.
5. B. Croft, D. Metzler, T. Strohman, Search Engines: Information Retrieval in Practice, Addison Wesley

| CS313 | Text Mining | L | T | P |
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**Basics of Text Processing:** Statistical and Graphical NLP; Representation; Boolean and Vector Space Models; Feature Selection; Stop Words; Stemming; Parts of Speech Tagging; Graph Based Representations; IR view of Text Processing; Similarity measures; Notion of Information Need, Precision and Recall.

**Classification and Clustering:** Supervised and Unsupervised methods for Text Processing; Classification Methods such as Naïve Bayes, Nearest Neighbour, Rochio's and Support Vector Machines; Clustering Methods such as Partitional and Hierarchical, Soft and Hard, K-Means, EM, Agglomerative Clustering; Datasets and Performance Measures.

**Applications:** Information Extraction; Named Entity Recognition; Question Answering; Sentiment Analysis; Semantic Annotation; Document Summarization.

***Suggested Readings:***


1. C. D. Manning, P. Raghvan, H. Schutze, Introduction to Information Retrieval, CUP.
2. R. Mihalcea, D. Radev, Graph based Natural Language Processing and Information Retrieval, CUP.
3. U.S. Tiwary, T. Siddiqui, Natural Language Processing and Information Retrieval, OUP.
4. G. S. Ingersol, T. S. Morton, A. L. Farris, Taming Text: How to Find, Organize and Manipulate It, Manning Publications.
5. S. Bird, E. Klein, E. Loper, Natural Language Processing with Python, O'Reilly.


| CS314 | Quantitative Science Studies | L | T | P |
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**Introduction**: Introduction to Scientometrics and Informetrics, Metrics in Science, The quantitative vs qualitative study of Science.

**Bibliometric Data Sources**: Scholarly Databases- Web of Science, Scopus, Dimensions, Google Scholar, Newer Data sources, Data Cleaning and Processing.

**Scientometric Indicators**: Research Productivity, Citation Indicators, Journal Indicators, Field Normalization, Institutional Rankings, Responsible use of Metrics.

**Collaboration in Science**: Co-authorship, Regional and International Collaboration, Network approaches to measuring and characterizing collaboration.

**Mapping and Visualization**: Scientometric studies at different levels, Visualization Tools and Techniques.

**Text-based Analysis**: Keywords and key-phrases, Subject Classification, Concept Density Maps, Thematic Clustering.

**Altmetrics**: Scientific Discourse in Social Media, Academic Social Networks, Correlation in Citation and Altmetrics, Studies in Altmetrics and their impact.

**Applications**: Scientometrics as evidence for Science Policy, Performance-based Funding, International Rankings, Open Science.

***Suggested Readings:***


1. B. Cronin, C. R. Sugimoto (Eds.) Beyond Bibliometrics: Harnessing Multidimensional Indicators of Scholarly Impact. MIT Press. 2014.
2. W. Glänzel, H.F. Moed, U. Schmoch, M. Thelwall (Eds.) Springer Handbook of Science and Technology Indicators, Springer, 2019.
3. J. Qiu, R. Zhao, S. Yang, K. Dong, Informetrics: Theory, Methods and Applications, Springer, 2017.
4. C. R. Sugimoto, Theories of Informetrics and Scholarly Communication, De Gruyter Saur, 2016 https://doi.org/10.1515/9783110308464
5. C. Daraio, W. Glänzel (Eds.), Evaluative Informetrics: The Art of Metrics-Based Research Assessment, Springer, 2020.
6. S. L. Sangam, Scientometrics: Quantitative Methods for Library and Information Science, 2015
7. P. Vinkler, The Evaluation of Research by Scientometric Indicators, Chandos Publishing, 2010.
8. L. Leydesdorff, The Challenge of Scientometrics: The Development, Measurement, and Self-Organization of Scientific Communications, Universal Publishers, 2001.


| CS315 | Statistical Learning | L | T | P |
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**Introduction**: Introduction to statistical learning, Estimation, Trade-off between prediction accuracy and model interpretability, Supervised versus Unsupervised learning, Regression versus Classification problems, Assessing model accuracy.

**Linear Regression**: Simple Linear Regression, Multiple Linear Regression, Other considerations in the Regression Model, Comparison with K-Nearest Neighbor.

**Classification**: Overview, Logistic Regression, Linear Discriminant Analysis, Comparison of Classification Methods.

**Resampling Methods**: Cross Validation, Bootstrap.

**Linear Model Selection and Regularization**: Subset Selection, Shrinkage Method, Dimension Reduction Methods, Considerations in High Dimensions.

**Moving Beyond Linearity**: Polynomial Regression, Step Functions, Basis Functions, Regression Splines, Smoothing Splines, Local Regression.

**Tree Based Methods**: Basics of Decision Trees, Bagging, Random Forests, Boosting.

**Unsupervised Learning**: Challenge of Unsupervised Learning, Principal Component Analysis.

***Suggested Readings:***


1. J. Gareth, W. Daniela, H. Trevor, T. Robert, An introduction to statistical learning with applications in R, Springer.
2. H. Trevor, T. Robert, F. Jerome. The Elements of Statistical Learning, Springer
3. M. A. Ponti, R. F. d. Mello, Machine Learning: A Practical Approach on the Statistical Learning Theory, Springer


| CS316 | Big Data Analytics | L | T | P |
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**Introduction to big data**: Big Data - Why and Where, Characteristics of Big Data and Dimensions of Scalability, Introduction to Big Data Platform, Challenges of Conventional Systems, Intelligent data analysis, Nature of Data, Analytic Processes and Tools, Analysis vs Reporting.

**Mining data streams**: Introduction To Streams Concepts, Stream Data Model and Architecture, Stream Computing, Sampling Data in a Stream, Filtering Streams, Counting Distinct Elements in a Stream, Estimating Moments, Counting Oneness in a Window, Decaying Window, Real Time Analytics Platform(RTAP) Applications, Real Time Sentiment Analysis, Stock Market Predictions.

**Hadoop and Spark**: History of Hadoop, Components of Hadoop, Analysing the Data with Hadoop, Hadoop Distributed File System(HDFS), Design of HDFS, Developing a Map Reduce Application, Job Scheduling, Shuffle and Sort, Task execution, Map Reduce Types and Formats, Hadoop Streaming. Introduction to Spark, Programming with RDDs, Spark SQL, Spark Streaming API, Spark ML Library. Hadoop Eco-System: Pig: Introduction to PIG, Execution Modes of Pig, Comparison of Pig with Databases, Grunt, Pig Latin, User Defined Functions, Data Processing operators. Hive: Hive Shell, Hive Services, Hive Metastore, Comparison with Traditional Databases, HiveQL, Tables, Querying Data and User Defined Functions. Hbase: Basics, Concepts, Clients, Example, Hbase Versus RDBMS. ZooKeeper, IBM InfoSphereBigInsights and Streams.

**Data Storage and Management**: NoSQL, PostgreSQL, Riak, CouchDB, NEO4J, Key-value and document data models, Google Big Table, Amazon S3, MongoDB, HBase, Cassandra, Consistency Models-Types of Consistency - Consistency of MongoDB, HBase and Cassandra.

***Suggested Readings:***


1. M. Berthold, D. J. Hand, Intelligent Data Analysis, Springer, 2007.
2. T. White, Hadoop: The Definitive Guide, Third Edition, O'reilly Media, 2012.
3. C. Eaton, D. DeRoos, T. Deutsch, G. Lapis, P. Zikopoulos, Understanding Big Data: Analytics for Enterprise Class Hadoop and Streaming Data, McGrawHill Publishing, 2012.
4. A. Rajaraman, J. D. Ullman, Mining of Massive Datasets, CUP, 2012.
5. B. Franks, Taming the Big Data Tidal Wave: Finding Opportunities in Huge Data Streams with Advanced Analytics, John Wiley& sons, 2012.
6. J. Han, M. Kamber, Data Mining Concepts and Techniques, 2nd Edition, Elsevier, Reprinted 2008.
7. G. J. Myatt, Making Sense of Data, John Wiley & Sons, 2007.
8. P. Warden, Big Data Glossary, O'Reilly, 2011.
9. D. Ruan, G. Chen, E. E.Kerre, G. Wets, Intelligent Data Mining, Springer, 2007.
10. P. Zikopoulos, D. Roos, K. Parasuraman, T. Deutsch, J. Giles, D. Corrigan, Harness the
11. Power of Big Data The IBM Big Data Platform, Tata McGraw Hill Publications, 2012.


| **CS321** | **Artificial Neural Networks** | **L** | **T** | **P** |
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**Introduction**: Biological Neural Networks, Mathematical Model of Neuron, McCulloch and Pitts Model, Concepts of Threshold and Activation Functions, Typically used Non-linearity, Stability-plasticity dilemma.

**ANN Topologies and Learning**: Rosenblatt Perceptron, Linear Separation and MLP, Feed-forward and Feed-backward Networks; Delta and Gradient Descent learning rules, Hebbian Learning, Back Propagation learning, Radial basis Function Networks, Associative Memory Paradigms, Hopfield Networks, Recurrent Networks, Self-organizing feature Maps.

**Applications**: ANN for Pattern Classification, Pattern Matching and Time Series Analysis.

***Suggested Readings:***


1. L. Fausett et al., Fundamentals of Neural Networks, Pearson.
2. S. Haykin, Neural Networks, Pearson.
3. M. T. Hagan, Neural Network Design, Cengage


| CS322 | Deep Learning | L | T | P |
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**Linear Algebra Review**: Brief review of concepts from Linear Algebra.

**Optimization**: Types of errors, bias-variance tradeoff, overfitting-underfitting, a brief review of concepts from Vector Calculus and optimization, variants of gradient descent, momentum.

**Logistic Regression**: Basic concepts of regression and classification problems, linear models addressing regression and classification, maximum likelihood, logistic regression classifiers.

**Neural Networks**: Basic concepts of artificial neurons, single and multilayer perceptrons, perceptron learning algorithm, its convergence proof, different activation functions, softmax cross-entropy loss function.

**Recurrent Neural Networks**: Discussion on Recurrent Neural Networks (RNNs), Long-Short, Term Memory (LSTM) architectures, and basics of word embedding.

Deep Reinforcement Learning, Autoencoders (standard, denoising, contractive, etc).

**ConvNets**: Basic concepts of Convolutional Neural Networks starting from filetering. Convolution and pooling operation and arithmetics of these.

**ConvNet Architectures**: Discussions on famous convnet architectures - AlexNet, ZFNet, VGG, C3D, GoogLeNet, ResNet, MobileNet-v1.

***Suggested Readings:***

1. I. Goodfellow, Y. Bengio, A. Courville, Deep Learning, MIT Press, 2016. (http://www.deeplearningbook.org)
2. M. A. Nielsen, Neural networks and deep learning. Vol. 2018, Determination press, 2015.,Determination press San Francisco, CA.
3. F. Chollet. Deep Learning with Python, Manning, 20117.
4. H. Jones, Deep Learning: An Essential Guide to Deep Learning for Beginners Who Want to Understand How Deep Neural Networks Work and Related to Machine Learning and Artificial Intelligence, Createspace Independent Publishing, 2018.

| CS323 | Human Computer Interaction | L | T | P |
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Introduction, History of HCI, Aspect of Human Cognition, The Computer, Models of Interaction.

HCI Frameworks, HCI Paradigms, Usability Principles, Design of Everyday Things.

Intro Human Abilities, Predictive Evaluation, Interpretive Evaluation, Task Analysis, Empirical Evaluation, Gathering Usability Data, Usability Specification.

Usability, Design Process, HCI issues in Software Engineering, UI Agents

Organisational Impact, Groupware, Pervasive Computing, Future Applications and Conclusion

***Suggested Readings:***

1. I. S. Mackenzie, Human-Computer Interaction: An Empirical Research Perspective, Elsevier Science, 2012.
2. J. Preece, Y. Rogers, H. Sharp, D. Benyon, S. Holland, T. Carey, Human-Computer Interaction: Concepts And Design (ICS), ADDISION-WESLEY, 1994.
3. B. Shneiderman, C. Plaisant, Designing the user interface: strategies for effective human-computer interaction, Pearson, 2010.

| CS324 | Heuristics & Metaheuristics | L | T | P |
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**Introduction**: State Space Search, Traditional vs Heuristic Search

**Review of Single State Methods**: Hill Climbing, Tabu Search, Iterated Local Search.

**Introduction to Evolutionary Algorithms and Genetic Algorithms**: Genetic Algorithms-Representation & Encoding, Operators, Convergence, Steady State vs Generational GA, Elitism, Grouping Genetic Algorithm; Variants and Hybrids; Estimation of Distribution Algorithms (EDAs).

**Swarm Intelligence Based Methods**: Basic concepts, Ant-Colony Optimization, Artificial Bee Colony Algorithm, Particle Swarm Optimization- Representation, Algorithmic Approach, Local and Global Best.

**Hyper-heuristic**: Automation of heuristics, Incorporation of machine learning techniques, Selection, Combination, Generation or adaptation of several simpler heuristics.

Basic idea about Variable Neighborhood Search, Simulated Annealing, GRASP, Differential Evolution- Representation, Operators, Algorithm and Harmony Search.

**Combinatorial Optimization Problems**: Characteristics of COPs, Categories of COPs.

Multi-objective Optimization, Laboratory Exercises and Applications.

***Suggested Readings:***


1. D. E. Goldberg, Genetic Algorithm in Search Optimization and Machine Learning, Pearson Education, 1989.
2. M. Mitchell, An Introduction to Genetic Algorithms, PHI,1998.
3. M. Dorigo and T. Stützle, Ant-Colony Optimization, PHI, 2004.
4. F. Glover and M. Laguna, Tabu Search, Kluwer Academic Publisher, 1997.
5. S. Luke, Essentials of Metaheuristics, 2015. (http://cs.gmu.edu/~sean/book/metaheuristics/).
6. El-Ghazali Talbi, Metaheuristics: From Design to Implementation, Wiley, 2009.
7. R. Eberhart, Y. Shi, J. Kennedy, Swarm Intelligence, Morgan Kauffman, 2001.
8. P. Larrañaga, J.A. Lozano, Estimation of Distribution Algorithms a New Tool for Evolutionary Computation, Boston, MA: Springer US, 2002.
9. K. Deb, Multi-objective Optimization using Evolutionary Algorithms, Wiley, 2001.


| CS325 | Fuzzy Logic and Applications | L | T | P |
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**Foundation of Fuzzy Set theory**: Basic Concepts and Properties of Fuzzy Set, Basic Types of Fuzzy Set, Properties of Fuzzy Sets, Representation and Constructing of Fuzzy Sets, Extension Principle for Fuzzy Sets, Operation on Fuzzy sets, Elements of Fuzzy Mathematics, Fuzzy Relation and Linguistic Variables.

**Fuzzy Logic**: Brief Overview of Classical Logic, Elements of Fuzzy Logic, Semantic Analysis of Different Fuzzy Logics, Fuzzy Inference Rules and Approximate Reasoning, Formalization of the Fuzzy Conditional Inference for Different Type of Conditional Propositions.

**Application of Fuzzy Sets**: Fuzzy Modeling, Fuzzy Decision Making, Pattern Analysis and classification, Fuzzy Control Systems and any other recent applications

***Suggested Readings:***


1. T. J. Ross, Fuzzy Logic with Engineering Applications, Wiley, third edition, 2004.
2. G. J. Klir and Bo Yuan, Fuzzy Sets and Fuzzy Logic: Theory And Applications, Prentice Hall, 1995.
3. F. M. Mcneill and Ellen Thro, Fuzzy Logic: A Practical Approach, Academic Press, 2014.


| CS331 | Wireless Sensor Networks | L | T | P |
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**Introduction and Overview of Wireless Sensor Networks**: Background of Sensor Network, Characteristics, Challenges and Constraints, Applications of WSN, Node Architecture, Operating Systems, Layered Architecture, Sensor network comparison with Ad Hoc Networks.

**Medium Access Control**: Overview, Wireless MAC Protocols, Characteristics of MAC Protocols in WSN, Objectives of MAC design, Energy efficiency in MAC design, Contention-free MAC Protocols, Contention-based MAC Protocols, Hybrid Protocols.

**Routing and Transport issues**: Overview, Fundamentals and Challenges of Routing protocol, Routing Metrics, Flooding and Gossiping, Data-Centric Routing, Proactive Routing, On-Demand Routing, Hierarchical Routing, Location-Based Routing, QoS based Routing, Data aggregation mechanisms. Traditional transport protocols, Transport protocols for sensor networks.

**Deployment and Configuration**: Clustering Techniques in WSN: Topology discovery and clusters in WSN, Node Clustering structures, Node Clustering algorithms. Localization and Positioning, Single-hop Localization, Positioning in Multi-hop environments, Coverage and Connectivity, Naming and Addressing in Sensor Networks, Assignment of MAC addresses.

**Future Trends in WSN**: Wireless Multimedia Sensor Networks, Underwater Acoustic Sensor Networks, Underground Sensor Networks, Body Area Sensor Network, Cross-Layer Design for WSN.

***Suggested Readings***:


1. H. Karl, A. Willig, Protocols and Architectures for Wireless Sensor Networks, John Wiley & Sons, India, 2012.
2. W. Dargie, C.Poellabauer, Fundamentals of Wireless Sensor Networks Theory and Practice, John Wiley and Sons , 2010.
3. S. Kazem, D. Minoli, T. Zanti, Wireless Sensor Network: Technology, Protocols and Application, John Wiley and Sons 1st Ed., 2007.


| CS332 | Mobile Adhoc Networks | L | T | P |
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**Ad-hoc Wireless Networks**: Introduction, cellular and ad-hoc wireless networks, applications of ad-hoc wireless networks, issues in ad-hoc wireless networks, ad-hoc wireless internet.

**MAC Protocols**: Introduction, issues in designing a MAC protocol, design goals of a MAC protocol, classifications of MAC protocols, contention-based protocols, contention-based protocols with reservation mechanisms, contention-based MAC protocols with scheduling mechanisms, MAC protocols that use directional antennas.

**Routing Protocols**: Introduction, issues in designing a routing protocol, classifications of routing protocols, table-driven routing protocols, on-demand routing protocols, hybrid routing protocols, routing protocols with efficient flooding mechanisms, hierarchical routing protocols, power-aware routing protocols.

**Multicast Routing Protocols**: Introduction, issues in designing a multicast routing protocol, operation of multicast routing protocols, an architecture reference model for multicast routing protocols, classifications of multicast routing protocols, tree-based multicast routing protocols, mesh-based multicast routing protocols, energy-efficient multicasting, multicasting with quality of service guarantees, application-dependent multicast routing.

**Transport Layer and Security Protocols**: Introduction, issues in designing a transport layer protocol, design goals of a transport layer protocol, classification of transport layer solutions, TCP over ad-hoc wireless networks, other transport layer protocols, security in ad-hoc wireless networks, network security requirements, issues and challenges in security provisioning, network security attacks, key management, secure routing protocols.

**Extension of MANET**: Vehicular ad-hoc networks, Delay tolerant networks, Opportunistic networks etc.

***Suggested Readings***:


1. C. Siva Ram Murthy, B. S. Manoj, Ad hoc Wireless Networks: Architectures and protocols, 2nd edition, Pearson Education. 2007.
2. C. E. Perkins, Ad hoc Networking, Addison – Wesley, 2000.
3. S. Basagni, M. Conti, S. Giordano, I. Stojmenovic, Mobile ad-hoc networking, Wiley-IEEE press, 2004.
4. M. Ilyas, The handbook of ad-hoc wireless networks, CRC press, 2002.


| CS333 | Software Defined Networks | L | T | P |
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**SDN Background and Motivation**: Evolving network requirements-The SDN Approach: Requirements, SDN Architecture, Characteristics of Software-Defined Networking, SDN and NFV-Related Standards: Standards-Developing Organizations, Industry Consortia, Open Development Initiatives.

**SDN Data plane and OpenFlow**: SDN data plane: Data plane Functions, Data plane protocols, Openflow logical network Device: Flow table Structure, Flow Table Pipeline, The Use of Multiple Tables, Group Table- OpenFlow Protocol.

**SDN Control Plane**: SDN Control Plane Architecture: Control Plane Functions, Southbound Interface, Northbound Interface, Routing, ITU-T Model- OpenDaylight- REST- Cooperation and Coordination among Controllers.

**SDN Application Plane**: SDN Application Plane Architecture: Northbound Interface, Network Applications, User Interface- Network Services Abstraction Layer: Abstractions in SDN, Frenetic- Traffic Engineering Measurement and Monitoring- Security- Data Center Networking- Mobility and Wireless.

**Network Functions Virtualization**: Background and Motivation for NFV- Virtual Machines- NFV Concepts: Simple Example of the Use of NFV, NFV Principles, High-Level

NFV Framework, NFV Benefits and Requirements- NFV Reference Architecture: NFV Management and Orchestration.

***Suggested Readings***:


1. W. Stallings, Foundations of Modern Networking, Pearson Ltd., 2016.
2. P. Goransson, C. Black, Software Defined Networks: A Comprehensive Approach, Morgan Kaufmann Publications, 2014.
3. T. D. Nadeau, K. Gray, SDN - Software Defined Networks, O'Reilly, 2013.


| CS334 | Network Security | L | T | P |
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| | | 2 | 1 | 1 |

**Introduction**: Computer Security Concepts, The OSI Security Architecture, Security Attacks, Security Services, Security Mechanisms, A Model for Network Security.

**Symmetric Encryption and Message Confidentiality**: Symmetric Encryption Principles, Symmetric Block Encryption Algorithms, Stream Ciphers and RC4, Cipher Block Modes of Operation.

**Public-Key Cryptography and Message Authentication**: Approaches to Message Authentication, Secure Hash Functions, Message Authentication Codes, Public-Key Cryptography Principles, Public-Key Cryptography Algorithms, Digital Signatures.

**Key Distribution and User Authentication**: Symmetric Key Distribution Using Symmetric Encryption, Kerberos, Key Distribution Using Asymmetric Encryption, X.509 Certificates.

**Transport-Level Security**: Web Security Considerations, Secure Socket Layer and Transport Layer Security, HTTPS, Secure Shell (SSH).

**IP Security**: Overview of IP Security (IPSec), IP Security Architecture, Modes of Operation, Security Associations (SA), Authentication Header (AH), Encapsulating Security Payload (ESP), Internet Key Exchange.

**Web Security**: Web Security Requirements, Secure Socket Layer (SSL), Transport Layer Security (TLS), Secure Electronic Transaction (SET).

**Electronic Mail Security**: Threats to E-Mail, Requirements and Solutions, Encryption for Secure E-Mail, Secure E-Mail System.

***Suggested Readings:***


1. W. Stalling, Network security, essentials, Pearson education Asia publication.
2. W. Stallings, Cryptography and Network Security: Principles and Practice, Pearson.
3. B. A. Forouzan, Cryptography and Network Security, McGraw-Hill Education.


| CS335 | Distributed Systems | L | T | P |
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**Introduction**: Definition, Goals, Types of Distributed Systems, Distributed Computing Systems, Distributed Information Systems, Distributed Pervasive Systems, System Architectures, Architectures versus Middleware, Self-Management in Distributed.

**Processes & Communication**: Threads, Threads in Distributed Systems, Virtualization, Clients, Servers, Code Migration, Remote Procedure Call, Message-Oriented Communication, Stream-Oriented Communication, Multicast Communication.

**Naming**: Names, Identifiers, Addresses, Flat Naming, Structured Naming, Attribute-Based Naming.

**Synchronization**: Clock Synchronization, Logical Clocks, Mutual Exclusion, Centralized Algorithm, Decentralized Algorithm, Distributed Algorithm, Token Ring Algorithm, Global Positioning of Nodes, Election Algorithms.

**Consistency, Replication & Fault Tolerance**: Introduction, Reasons for Replication, Replication as Scaling Technique, Data-Centric Consistency Models, Client-Centric Consistency Models, Replica Management, Consistency Protocols, Process Resilience, Reliable Client-Server Communication, Reliable Group Communication, Distributed Commit, Recovery.

**Distributed Shared Memory & File Systems**: Hardware DSM, Design issues in DSM Systems, Implementation issues, Heterogeneous and Other DSM Systems, Distributed File Systems, File Service Architecture, Case Study: Sun Network File System, The Andrew File System.

***Suggested Readings:***


1. A. S. Tanenbaum, M. V. Steen, Distributed systems: principles and paradigms, Prentice-Hall.
2. G. F. Coulouris, J. Dollimore, T. Kindberg, Distributed Systems: Concepts and Design, Addison-Wesley.
3. M. Singhal, N. G. Shivaratri, Advanced concepts in operating systems, McGraw-Hill.


| **CS341** | **Image Processing** | **L** | **T** | **P** |
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**Digital Image Fundamental**: Elements of Visual Perception- Structure of the human eye, Image formation in the eye, brightness adaptation and discrimination; light and electromagnetic spectrum, image sensing and acquisition, image sampling and quantization, basic relationships between pixels, linear and nonlinear operations.

**Image Enhancement**:Point processing: Contrast stretching, power-law and gamma transformation. Histogram processing: histogram equalization and matching.

**Filtering and Restoration**:Degradation function and Noise Models, Spatial Domain Filtering: Correlation and Convolution, Smoothing Linear and Nonlinear Filters: Mean

and Median Filters, Adaptive Filtering, Sharpening Linear and Nonlinear Filters: Derivative, Laplacian, Unsharp Masking, High-boost Filtering. Frequency Domain Filtering: Filtering: Low-pass (Smoothing) & High-Pass (Sharpening) Ideal, Butterworth and Gaussian Filtering, Unsharp Masking and High-Boost Filtering, Homomorphic Filtering, Periodic Noise Reduction and Inverse Filtering & Wiener Filtering.

**Image Reconstruction from Projections**: Transmission tomography, reflection tomography, emission tomography, magnetic resonance imaging, and projection based image processing. Radon transform, back projection operator, projection theorem, inverse radon transform, convolution filter back projection, reconstruction from blurred noisy projections, Fourier reconstruction, fan-beam reconstruction, algebraic methods and three dimensional tomography.

**Image Compression**: Introduction, Error criterion- objective and subjective criterion; Lossy compression- transform domain compression, JPEG compression, block truncation compression, vector quantization compression; Lossless compression- Huffman coding, arithmetic coding, transformed coding, run-length coding, block coding, quad tree coding, and contour coding.

***Suggested Readings:***


1. A. K. Jain, Fundamentals of Digital Image Processing, Pearson Education India, 2015.
2. Rafael Gonzalez, Richard Woods, Digital Image Processing, Pearson Education India, 2017.
3. R. H. Vollmerhausen, R.G. Driggers, Analysis of Sampled Imaging Systems, SPIE Press, 2001.
4. B. Chanda, D. D. Majumder, Digital Image Processing and Analysis, PHI, 2011.
5. A. C. Bovik, Handbook of Image and Video Processing (Communications, Networking & Multimedia). Academic Press, 2005.
6. J. S. Lim, Two Dimensional Signal and Image Processing, Prentice-Hall, Englewood Cliffs, New Jersey, 1989.
7. D. E. Dudgeon, Russell M. Mersereau, Multidimensional Signal Processing, Prentice Hall, 1983.
8. S. G. Wilson, Digital Modulation and Coding, Pearson Education, 2003.
9. H. Maître, From Photon to Pixel: The Digital Camera Handbook, Wiley- 2017.


| CS342 | Image Analysis and Computer Vision | L | T | P |
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**Morphological Image Processing**: Basic concept of set theory, logic operation involving binary images, dilation and erosion, opening and closing, and hit-or-miss transformation. Some basic morphological algorithms – Boundary extraction, region filling, extraction of connected components, convex hull, thinning, thickening, skeletons, and pruning. Extensions to gray-scale images – Dilation, Erosion, Opening and closing, and application of gray scale morphology.

**Image Segmentation**: Detection of discontinuities – Point detection, line detection, edge detection – gradient operators, compass operators, Laplace operators and zero crossing, stochastic gradients, performance of edge detector operators. Amplitude

thresholding or window slicing, component labeling, boundary based approaches, region-based approaches and clustering, template matching, and texture segmentation.

**Boundary Extraction and Representation**: Connectivity, Contour following, edge linking, Hough transform, chain code, fitting line segments, B-spline representation, Fourier descriptors, shape number, and autoregressive model.

**Region Representation**: Run-length codes, quad-trees, topological descriptor, texture and projections.

**Moment Representation**: Moment representation theorem, moment matching, orthogonal moments, moment invariants, applications of moment invariants.

**Shape feature**: Geometric features, moment-based features.

**Texture**: Statistical approaches, structural approaches, and other approaches.

**Scene matching**: Image subtraction, template matching and area correlation, and matched filtering.

**Object recognition and image understanding**: Patterns and pattern classes, decision theoretic and structural methods.

***Suggested Readings:***


1. A. K. Jain, Fundamentals of Digital Image Processing, Pearson Education India, 2015.
2. R. Gonzalez, Richard Woods, Digital Image Processing, Pearson Education India, 2017.
3. M. Sonka, V. Hlavac, R. Boyle, Image Processing, Analysis and Machine Vision, Cl-Engineering , 2014..
4. B. Chanda, D. . Majumder, Digital Image Processing and Analysis, ISBN: 978-81-203-4325-2, PHI, 2013,
5. D. Forsyth, J.Ponce, Computer Vision: A Modern Approach, Pearson, 2015.
6. R. Szeliski, Computer Vision: Algorithms and Applications, Springer, 2010.
7. S. J. D. Prince, Computer Vision: Models, Learning, and Inference, Cambridge University Press, 2012.
8. R. Hartley, A. Zisserman, Multiple View Geometry in Computer Vision, Cambridge University Press, 2004.
9. P. Soille, Morphological Image Analysis: Principles and Applications, Springer, 2010.


| CS343 | Compressive Sensing and Applications | L | T | P |
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**Introduction**: Introduction to compressive sensing.

**Sparse and Compressible Signal Models**: Introduction to vector spaces, Bases and frames, Sparse representations, and Compressible signals.

**Sensing Matrices**: Sensing matrix design, Null space conditions, The restricted isometry property, The RIP and the NSP, Matrices that satisfy the RIP, and Coherence

**Sparse Signal Recovery via Minimization**: Signal recovery via minimization, Noise-free signal recovery, Signal recovery in noise, Instance-optimal guarantees revisited, and The cross-polytope and phase transitions.

**Algorithms for Sparse Recovery**: Sparse recovery algorithms, Convex optimization-based methods, Greedy algorithms, Combinatorial algorithms, and Bayesian methods.

**Applications of Compressive Sensing**: Linear regression and model selection, Sparse error correction, Group testing and data stream algorithms, Compressive medical imaging, Analog-to-information conversion, Single-pixel camera, Hyperspectral imaging, Compressive processing of manifold-modeled data, Inference using compressive measurements, Compressive sensor networks, Genomic sensing.

***Suggested Readings:***


1. S. Mallat, A Wavelet Tour of Signal Processing the Sparse Way, Academic Press, 2009.
2. S. Foucart, H. Rauhut, A Mathematical Introduction to Compressive Sensing: Applied Numerical Harmonic Analysis, Birkhäuser, 2013.
3. Y. C. Eldarc, Compressed Sensing: Theory and Applications, Cambridge University Press, 2012.
4. M. Lustig, D. L. Donoho, J. M. Santos, J. M. Pauly, Compressed Sensing MRI, IEEE Signal Processing Magazine, no. 2, pp. 72 – 82, 2008.
5. Computational MRI: Compressive Sensing Beyond, vol. 32, no. 1, 2020, IEEE Signal Processing Magazine.
6. A. D. M., Yonina C. Eldar, Alexander M. Haimovich, Compressed Sensing in Radar Signal Processing Cambridge University Press, 2019.
7. S. B. Lieven, Vandenberghe, Convex Optimization, Cambridge University Press, March 2004.
8. R. Baraniuk, M. A. Davenport, M. F. Duarte, C. Hedge, An Introduction to Compressive Sensing, online Rice University Resource, http://cnx.org/content/col11133/1.5
9. G. Kutyniok, Compressed Sensing: Theory and Applications, online Rice University Resource.
10. M. Fornasier, H. Rauhut, Compressive Sensing, online Rice University Resource. (http://dsp.rice.edu/cs)


| CS344 | Digital Signal Processing, Sensor And Systems | L | T | P |
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**Digital Signal and Systems**: Introduction to signals, systems and sensors, discrete-time signals and systems, Z-transform and its application to the analysis of LTI system, frequency analysis of signals and systems.

**Discrete Fourier Transform (DFT)**: DFT properties and applications, computational issues related to DFT and Fast Fourier Transform (FFT) algorithms, implementation of discrete time systems, digital filters. Multi-rate digital signal processing and its relation

with Multi resolution Analysis (MRA) using wavelet, linear prediction and optimum linear filters, power spectrum estimation

**Sensor and System**: Principle of the EEG and ECG system, Optical imaging sensors and system, X-ray sensor and system, Computed Tomography (CT) system, Magnetic resonance imaging system (MRI).

***Suggested Readings:***


1. J. G. Proakis, D. G. Manolakis, Digital Signal Processing - Principles, Algorithms and Application (3rd edition), Pearson Education, 2004.
2. A. V. Oppenheim, Signals and Systems (2nd edition), Pearson Education,2015.
3. A. V. Oppenheim, Ronald W. Schafer, Digital Signal Processing, Pearson Education, 2008.
4. E. Seeram, Computed Tomography: Physical Principles, Clinical Applications, and Quality Control, Saunders, 2015.
5. Computational MRI: Compressive Sensing Beyond, vol. 32, no. 1, 2020, IEEE Signal Processing Magazine.
6. R. M. Rangayyan, Biomedical Signal Analysis- A Case-Study Approach, IEEE Press, 2005.
7. D. C. Reddy, Biomedical Signal Processing – Principles and Techniques, Tata McGraw-Hill, New Delhi, 2009.
8. H. Maître, From Photon to Pixel: The Digital Camera Handbook, Wiley- 2017.
9. A. K. Jain, Fundamentals of Digital Image Processing, PHI, 1995.
10. R. H. Vollmerhausen, R.G. Driggers, Analysis of Sampled Imaging System, SPIE Press, 2001.


| CS345 | Speech Processing and Recognition | L | T | P |
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**Introduction to Digital Speech Processing**: Review of DSP fundamentals, acoustic theory of speech production, speech perception--auditory models, sound perception models, MOS methods, sound propagation in the vocal tract.

**Speech Coding and Synthesis**: Time domain methods in speech processing, methods of pitch period estimation, speech representations based on STFT, homomorphic speech processing, linear predictive coding (LPC) methods, model-based speech coding method, cepstral analysis.

**Speech Enhancement**: Introduction, classification of speech enhancement methods, short-term spectral amplitude techniques, speech modeling and Wiener filtering, speech enhancement and All-Pol modeling, sequential estimation via EM theory.

**Speech Quality Assessment**: Quality versus intelligibility. subjective quality measures - intelligibility tests, quality tests. Objective quality measures - Articulation index, signal-to-noise ratio, Itakura measure, other measures based on LP analysis, weighted-spectral slope measures, global objective measures, objective versus subjective measures.

**Speech Recognition Problem**: Speaker-dependent versus speaker-independent recognition, vocabulary size, isolated-word versus continuous-speech recognition,

linguistic constraints, acoustic ambiguity and confusability, environmental noise, speaker recognition and verification. dynamic time warping, Hidden Markov Model(HMM) based speech modeling, N-Gram statistical models, standard databases for speech-recognition research.

***Suggested Readings:***


1. J. R. Deller, J. G. Proakis, J. ohn H. LHansen, Discrete-Time Processing of Speech Signals, Wiley India, 2010.
2. L. R. Rabiner, R.W Schafer, Digital Processing of Speech Signals, Pearson Education India, 2003.
3. L. R. Rabiner, Yegnararayana, Fundamentals of Speech Recognition, Pearson Education India, 2008.
4. F. Jelinek, Statistical Methods for Speech Recognition, MIT Press, 1998.
5. S. Furui, Digital Speech Processing: Synthesis, and Recognition, CRC Press, 2018.
6. P. C. Loizou, Speech Enhancement: Theory and Practice, CRC Press, 2017.
7. T. F. Quatieri, Discrete -Time Speech Signal Processing: Principles and Practice, Pearson Prentice Hall, 2008.
8. X. Huang, J. Baker, R. Reddy, A Historical Perspective of Speech Recognition Communications of the ACM, January, vol. 57, no. 1, pp. 94-103, 2014.


| CS346 | Statistical Pattern Recognition | L | T | P |
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**Introduction**: Description of patterns, Probabilistic formulation of PR, Geometrical interpretation, Applications of PR, Scope of statistical PR.

**Linear and nonlinear classification theory**: Elementary Bayes decision theory, statistical criterion and discriminant functions, linear decision functions, piecewise linear decision functions, minimum distance classifier, nonlinear classification theory, multiple pattern classification.

**Representation of patterns**: Representation of binary random patterns – Orthogonal series expansion procedures, and Markov dependence considerations. KL expansion of patterns and its properties.

**Feature Selection and Extraction**: Information measures of feature effectiveness, Distance measure and performance bounds, Multiclass distance measures, feature selection criterion, Evaluation of feature subset, Algorithm of dimensionality reduction, dimensionality and sample size.

**Supervised and Unsupervised Learning**: Bayesian estimation for Gaussian patterns, Comments on supervised Bayesian estimation, parameter estimation of slowly varying patterns, Bayes solution to unsupervised estimation, Estimation of mixture parameters, and decision-directed estimation. Graph theoretic method, independent component analysis – ICA, PCA, Artificial neural network.

**Recursive Algorithm using Stochastic Approximation**: Supervised parameter estimation using stochastic approximation, Estimation of probability density function, Unsupervised estimation using stochastic approximation.

**Nonparametric methods and compound decision theory**: Basic concepts and tools, Sample set construction, Nearest – Neighbor decision procedure, compound decision procedure, nonparametric estimation of multivariate density function, and nonparametric feature selection.

**Cluster and Mode-Seeking Techniques**: Distance and similarity measures, clustering methods.

**Sequential pattern recognition systems**: Bayes sequential decision procedure and the computational problems, Sequential probability ratio test (SPRT) and generalized sequential probability ratio test (GSPRT), Bayes sequential analysis, Feature-ordering and selection problems, and Nonparametric sequential ranking procedure.

**Contextual Analysis in PR**: Bayes decision making in Markov chains, compound decision theory for contextual analysis, a practical context algorithm for image interpretation.

**Recognition with strings**: Strings matching, edit distance, computational complexity, string matching with errors, string matching with 'don't care' symbols. Grammatical method, grammatical interface, rule based methods.

***Suggested Readings:***


1. A. K. Jain, Fundamentals of digital image processing, PHI, 1995.
2. R.C. Gonzalez, R. Woods, Digital Image Processing, Prentice Hall, 2008.
3. R.O. Duda, P.E. Hart and D.G. Stork, Pattern Classification, Wiley and Sons,2001.
4. S. Theodoridis and K. Koutroumbas, Pattern Recognition, Academic Press, 1999.
5. T. M. Mitchell, Machine Learning, Mcgraw-Hill, 1997.
6. N. Crisitanini, J. Shawe-Taylor, An introduction to Support Vector Machines, Cambridge Press, 2000.
7. B. SchÖlkopf, A. J. Smola, Learning with Kernels, MIT Press, 2002.
8. D. Barber, Bayesian Reasoning and Machine Learning, Cambridge University Press, 2012
9. D. Koller, N. Friedman, Probabilistic Graphical ModelsPrinciples and Techniques, MIT Press, 2009.


| CS351 | Parallel Computing | L | T | P |
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**Introduction to Parallel Computing**: Supercomputers and grand challenge problems, Modern Parallel Computers, Data Dependence Graph, Data Parallelism, Functional Parallelism, Pipelining and Data Clustering.

**Interconnection Networks**: Switch Network Topologies, Direct and Indirect Network Topology, Bus, Star, Ring, Mesh, Tree, Binary Tree Network, Hyper Tree Network, Hybrid, Hypercube, Perfect Shuffle Network, Torus and Butterfly Network.

**Performance Analysis**: Introduction, Execution Time, Speedup, Linear and Superlinear Speedup, Efficacy and Efficiency, Amdahl's Law and Amdahl Effect, Gustafson-Barsis's

Law, Minsky's Conjecture, The Karp-Flatt Metric, The Isoefficiency Metric, Isoefficiency Relation, Costand Scalability.

**Parallel Computational Models**: Flynn's Taxonomy, PRAM, EREW, CREW, ERCW, CRCW, Simulating CRCW, CREW & EREW, PRAM algorithms.

**Introduction to Parallel Algorithms**: Parallel Programming Models, PVM, MPI Paradigms, Parallel Programming Language, Brent's Theorem, Simple parallel programs in MPI environments, Parallel algorithms on network, Addition of Matrices, Multiplication of Matrices.

***Suggested Readings:***


1. F. A. Briggs, K. Hwang, Computer Architecture and Parallel Processing, McGraw Hill.
2. J. M. Crichlow, Introduction to Distributed and Parallel Computing, PHI.
3. M. J. Quinn, Designing Efficient Algorithms for Parallel Computers, McGraw-Hill.
4. V. Rajaraman, Elements of Parallel Computing, PHI.
5. J. JAJA, Introduction to Parallel Algorithms, Addison Wesley.
6. S. G. Akl, The Design and Analysis of Parallel Algorithms, PHI.
7. M. Sasikumar, D. Shikhare, R. P. Prakash, Introduction to Parallel Processing, PHI.
8. S. K. Basu, Parallel and Distributed Computation: Architectures and Algorithms, PHI.


| CS352 | Cloud Computing | L | T | P |
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Introduction to Parallel and Distributed Computing; Introduction to Cloud Computing; Characteristics and benefits of cloud computing; Historical developments and evolution of cloud computing: Distributed Systems, Virtualization, Web 2.0, Service-oriented computing, Utility Computing; Cloud Computing Reference Model.

Introduction to virtualization; Characteristics of virtualized environments; Taxonomy of virtualization techniques; Virtualization and cloud computing; Pros and cons of virtualization; Technology examples: Xen: paravirtualization, VMware: full virtualization, Microsoft Hyper-V.

Cloud Computing Architecture; Service models: Infrastructure as a Service (IaaS), Platform as a Service (PaaS), Software as a Service (SaaS); Deployment models: Public, Private, Hybrid, Community; IaaS: Introduction to IaaS, Resource Virtualization i.e. Server, Storage and Network virtualization; PaaS: Introduction to PaaS, Cloud platform & Management of Computation and Storage; SaaS: Introduction to SaaS, Cloud Services, Web services, Web 2.0, Web OS; Case studies related to IaaS, PaaS and SaaS.

Economics of the cloud; Open Challenges in Cloud Computing; Introduction to emerging computing paradigms and research challenges: Edge Computing, Mobile Cloud Computing, Fog Computing etc.; Introduction to IoT Cloud; Study on simulators related to cloud computing and emerging computing paradigms.

***Suggested Reading:***

1. R. Buyya, C. Vecchiola, S. ThamaraiSelvi, Mastering Cloud Computing, McGraw Hill Education.
2. B. Sosinsky, Cloud Computing Bible, Wiley.
3. K. Hwang, G. C. Fox, J.Dongarra, Distributed and Cloud Computing: From Parallel Processing to the Internet of Things, Morgan Kaufmann

| CS353 | Internet of Things | L | T | P |
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**Introduction to IoT**: Genesis of IoT, IoT and Digitization, IoT Challenges, Comparing IoT architectures, a simplified IoT architecture, The core IoT functional Stack, IoT data management and compute stack.

**Engineering for IoT Networks**: Sensors, Actuators, Smart Objects, Sensor Networks, IoT Access Technologies, IP as the IoT Network Layer, Applications protocols for IoT.

**Data and Analytics for IoT**: An introduction to data analytics for IoT, Machine Learning, Big data analytics tools and technology, edge streaming analytics, network analytics

**IoT in Industry**: Manufacturing, Oil and Gas, Utilities, Smart and Connected Cities, Transportation, Mining, Public Safety.

***Suggested Readings:***

1. D. Hanes, G. Salgueiro, P. Grossetete, R. Barton, J. Henry, IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Things, CISCO.
2. Rajkamal, Internet of Things, McGraw Hill Education.

| CS354 | Embedded Systems | L | T | P |
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**Embedded Computing**: Embedded System, Complex Systems and Microprocessor, Categories of Embedded Systems, Operating Systems for Embedded Systems, Embedded System Design, Embedded Processors, Hardware Units and Devices: Processor in the system, Other Hardware Units and Devices in a System, Linking and Interfacing Buses and Units.

**The 8051 Architecture**: 8051 microcontroller, I/O Ports and Circuits, Timers / Counters, Serial Interface, Interrupts, 8051 Assembly Language Programming, 8051 Instruction Set, Interfacings with 8051.

**Introduction to Real Time Operating Systems**: A Brief History of Operating Systems, Meaning and Types of operating system, Definition of RTOS, The Scheduler, Objects and Services, Key Characteristics of an RTOS.

**Tasks and Tasks States**: Definition of a Task, Task States and Scheduling, Task Operations, Task Structure, Synchronization and Communication.

**Semaphores**: Definition of Semaphore- Binary Semaphores, Counting Semaphores, Mutual Exclusion (Mutex) Semaphores; Typical Semaphore Operations, Typical Semaphore Use.

**Message Queues, Mailboxes and Pipes**: Message Queues, Mailboxes, Pipes, Event Registers, Signals, Condition Variables.

**Memory Management and Interrupt Routines in an RTOS Environment**: Memory Management, Timer Functions, Device I/O Management, Interrupt routines in an RTOS Environment, Basic design using an RTOS, Encapsulating Semaphores and Queues, Important Real Time operating Systems (RTOSs).

***Suggested Readings:***


1. R. Kamal, Embedded Systems Architecture Programming and Design Tata MC Graw-Hill.
2. T. Wilmshurst, Designing Embedded Systems with PIC Microcontrollers: principles and applications, Elsevier.
3. S. Heath, Embedded Systems Design, Newnes publications
4. T. Noergaard, Embedded Systems Architecture: A Comprehensive Guide for Engineers and Programmers, Elsevier.


| CS355 | Blockchain Technologies | L | T | P |
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**Basics**: Distributed Database, Two General Problem, Byzantine General problem and Fault Tolerance, Hadoop Distributed File System, Distributed Hash Table, ASIC resistance, Turing Complete.

**Cryptography**: Hash function, Digital Signature - ECDSA, Memory Hard Algorithm, Zero Knowledge Proof.

**Blockchain**: Introduction, Advantage over conventional distributed database, Blockchain Network, Mining Mechanism, Distributed Consensus, Merkle Patricia Tree, Gas Limit, Transactions and Fee, Anonymity, Reward, Chain Policy, Life of Blockchain application, Soft & Hard Fork, Private and Public blockchain.

**Distributed Consensus**: Nakamoto consensus, Proof of Work, Proof of Stake, Proof of Burn, Difficulty Level, Sybil Attack, Energy utilization and alternate.

**Cryptocurrency**: History, Distributed Ledger, Bitcoin protocols - Mining strategy and rewards, Ethereum - Construction, DAO, Smart Contract, GHOST, Vulnerability, Attacks, Sidechain, Namecoin

**Cryptocurrency Regulation**: Stakeholders, Roots of Bitcoin, Legal Aspects - Cryptocurrency Exchange, Black Market and Global Economy.

**Blockchain Applications**: Internet of Things, Medical Record Management System, Domain Name Service and future of Blockchain.

***Suggested Readings:***


1. A. Narayanan, J. Bonneau, E. Felten, A. Miller, S Goldfeder, Bitcoin and Cryptocurrency Technologies: A Comprehensive Introduction, Princeton University Press .
2. Wattenhofer, The Science of the Blockchain.
3. Antonopoulos, Mastering Bitcoin: Unlocking Digital Cryptocurrencies.
4. S. Nakamoto, Bitcoin: A Peer-to-Peer Electronic Cash System.
5. G. Wood, ETHEREUM: A Secure Decentralized Transaction Ledger, Yellow paper.2014.
6. N. Atzei, M. Bartoletti, T. Cimoli, A survey of attacks on Ethereum smart contracts.


| CS411 | Computational Tools & Techniques | L | T | P |
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This is the practical course. The candidates will undergo through hands on training in relevant computational tools/techniques/platforms and give one Seminar/Presentation.