Course Structures & Syllabi
for

Bachelor of Science (B.Sc.) Hons. in Computer Science

Master of Science (M.Sc.) in Computer Science

Master of Computer Applications (M.C.A.)

Doctor of Philosophy (Ph.D.)

(Applicable for the students admitted w.e.f. academic session 2020-21)

Department of Computer Science
Institute of Science
Banaras Hindu University

Courses in Computer Science

(List and Detailed Syllabus)

The department offers different kinds of courses at undergraduate, post-graduate and doctoral levels. The courses in the department are categorized into following five types:

1. Introductory/ Bridge Courses in Computer Sciences *(Course Codes 1XX)*
2. Core Courses in Computer Science *(Course Codes 2XX)*
3. Major Electives in Computer Science *(Course Codes 3XX)*
4. Activity-based/ Minor Elective Courses *(Course Codes 4XX)*
5. Application-based / Practice-based Courses (*Course Codes 5XX*)

List of Introductory/ Bridge Courses:

Course Code	Course Title	Credits
CS101	Problem Solving through C Programming	06
CS102	Digital Logic and Circuits	06
CS103	Numerical Computing	06
CS104	Computer Organization and Architecture	06
CS105	Discrete Mathematics	04
CS106	Operating System Concepts	04
CS107	Database Management Systems	06
CS108	Data Structures and Algorithms	06
CS109	Data Communication	04
CS110	System Analysis and Design	04
CS111	Computer Organization and Operating System	Non-credit
CS112	Mathematical Foundations of Computer Science	Non-credit

List of Core Courses:

Course Code	Course Title	Credits
CS201	Probability and Statistics for Computer Science	04
CS202	Theory of Computation	03
CS203	Design and Analysis of Algorithms	04
CS204	Object Oriented Programming	05
CS205	Software Engineering	03
CS206	Computer Networks	04
CS207	Compiler Design	04
CS208	Artificial Intelligence	04
CS209	Machine Learning	05
CS210	Advanced Course in Data Structures and Algorithms	04
CS211	Mathematical foundations of Computing	03

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

List of Activity-based/ Minor Elective Courses:

Course Code	Course Title	Credits
CS401	Communication Skills	02
CS402	Technical Writing & Seminar	02
CS403	Reading Elective A	02
CS404	Reading Elective B	02
CS405	Reading Elective C	02

CS406	Comprehensive Viva	02
CS407	Introduction to Information Technology	02
CS408	Fundamentals of Computing	02

List of Application-based / Practice-based Courses:

Course Code	Course Title	Credits
CS501	Minor Project	03
CS502	UG Project	12
CS503	Dissertation	16
CS504	Major Project	16
CS505	Industrial Training	16

Bachelor of Science (Computer Science Hons.)

Semester-wise Distribution of Courses and Credits

SEMESTER I		
Course Code	**Course Title**	**Credits**
CS101	Problem Solving through C Programming	06
	Total	**06**
SEMESTER II		
Course Code	**Course Title**	**Credits**
CS102	Digital Logic and Circuits	06
	Minor Elective I (Non CS-stream Students)	02
	Total	**06**
SEMESTER III		
Course Code	**Course Title**	**Credits**
CS103	Numerical Computing	06
	Total	**06**
SEMESTER IV		
Course Code	**Course Title**	**Credits**
CS104	Computer Organization and Architecture	06
	Minor Elective II (Non CS-stream Students)	02
	Total	**06**
SEMESTER V		
Course Code	**Course Title**	**Credits**
CS106	Operating System Concepts	04
CS107	Database Management Systems	06
CS108	Data Structures and Algorithms	06
CS110	System Analysis and Design	04
	Total	**20**
SEMESTER VI		
Course Code	**Course Title**	**Credits**
CS105	Discrete Mathematics	04
CS109	Data Communication	04
CS502	UG Project	12
	Total	**20**
	Grand Total	**64**

Master of Computer Science (M.Sc.)

Semester-wise Distribution of Courses and Credits

SEMESTER I		
Course Code	**Course Title**	**Credits**
CS201	Probability and Statistics for Computer Science	04
CS202	Theory of Computation	03
CS204	Object Oriented Programming	05
CS206	Computer Networks	04
CS401	Communication Skills	02
CS403	Reading Elective A	02
	Total	**20**
SEMESTER II		
Course Code	**Course Title**	**Credits**
CS203	Design and Analysis of Algorithms	04
CS208	Artificial Intelligence	04
CS3XX	Major Elective I	04
CS3XX	Major Elective II	04
CS402	Technical Writing & Seminar	02
CS404	Reading Elective B	02
	Total	**20**
SEMESTER III		
Course Code	**Course Title**	**Credits**
CS207	Compiler Design	04
CS209	Machine Learning	05
CS3XX	Major Elective III	04
CS3XX	Major Elective IV	04
CS501	Minor Project	03
	Total	**20**
SEMESTER IV		
Course Code	**Course Title**	**Credits**
CS405	Reading Elective C	02
CS406	Comprehensive Viva	02
CS503	Dissertation	16
	Total	**20**
	Grand Total	**80**

Master of Computer Application (MCA)

Semester-wise Distribution of Courses and Credits

SEMESTER I		
Course Code	**Course Title**	**Credits**
CS108	Data Structures and Algorithms	06
CS204	Object Oriented Programming	05
CS205	Software Engineering	03
CS206	Computer Networks	04
CS401	Communication Skills	02
CS111*	Computer Organization and Operating System	Non-credit
	Total	**20**
SEMESTER II		
Course Code	**Course Title**	**Credits**
CS107	Database Management Systems	06
CS208	Artificial Intelligence	04
CS3XX	Major Elective I	04
CS3XX	Major Elective II	04
CS403	Reading Elective A	02
CS112*	Mathematical Foundations of Computer Science	Non-credit
	Total	**20**
SEMESTER III		
Course Code	**Course Title**	**Credits**
CS209	Machine Learning	05
CS3XX	Major Elective III	04
CS3XX	Major Elective IV	04
CS402	Technical Writing & Seminar	02
CS404	Reading Elective B	02
CS501	Minor Project	03
	Total	**20**
SEMESTER IV		
Course Code	**Course Title**	**Credits**
CS405	Reading Elective C	02
CS406	Comprehensive Viva	02
CS504/ CS505	Major Project/ Industrial Training	16
	Total	**20**
	Grand Total	**80**

Doctor of Philosophy (Ph.D.) Coursework

Semester-wise Distribution of Courses and Credits

SEMESTER I		
Course Code	**Course Title**	**Credits**
FSCP-01*	Ethics in Science	01
FSCP-02*	Methods of Research and Good Laboratory Practices	01
FSCP-03*	Science Communication	01
CS210	Advanced Course in Data Structures and Algorithms	04
CS211	Mathematical Foundations of Computing	03
CS403	Reading Elective A	02
	Total	**12**
SEMESTER II		
Course Code	**Course Title**	**Credits**
CS3XX	Major Elective I	04
CS3XX	Major Elective II	04
CS404	Reading Elective B	02
	Total	**10**
	Grand Total	**22**

* Faculty-level course

CS101	Problem Solving through C Programming	L	T	P
		4	0	2

Introduction to Programming: Program development phases, Algorithms, Flow-charts, Types of Programming Languages, Interpreter, Compiler and Linker.

Constants, Variables, Data Types, Operators and Expressions: Character set, C Tokens, Identifiers and Keywords, Constants, Variables, Data types. Arithmetic operators, Relational operators, Logical operators, assignment operator, increment and decrement operators, Conditional operators, Arithmetic expressions, Operator precedence and associativity, Mathematical functions.

Managing Input & output operations: Reading a character, writing a character, Formatted input, and Formatted output.

Control Statements and Decision Making: if statement, if-else statement, Nesting of if statements, Conditional expression, switch case statement, while loop, do while loop, for loop, nesting of for loops, break statement and continue statement.

Functions, Array and String: User defined functions, Standard library functions, Passing values between functions, Calling convention, Return type of functions, Call by value and Call by reference, Recursive functions. One-dimensional array, Passing array to function, Two-dimensional array and Multidimensional array. String, declaring and initializing string variables, reading string from terminal, writing string to screen, implementation of string handling functions, array of strings.

Pointers and Storage Classes: Basics of Pointers, Pointers and One-dimensional Arrays, Pointer Arithmetic, Similarities between Pointers and One-dimensional Arrays, Null pointers, Pointers as Function Arguments, Pointers and Strings, Pointers and two-dimensional arrays, Arrays of Pointers. Storage Classes and Visibility, Automatic or local variables, Global variables, Static variables, External variables.

Structures, Unions and Pre-processor: Basics of Structures, Structures and Functions, Arrays of Structures, Pointers to Structures, Self-referential Structures, Unions. Preprocessor, File Inclusion, Macro Definition and Substitution, Macros with Arguments, Nesting of Macros, Conditional Compilation.

Dynamic Memory Allocation and File Management: Dynamic Memory Allocation, Allocating Memory with malloc and calloc functions, Freeing Memory, Reallocating Memory Blocks. File Management, Defining and Opening a file, Closing Files, Input/output Operations on Files, Predefined Streams, Error Handling during I/O Operations, Random Access to Files, Command Line Arguments.

Suggested Readings:

1. B. W. Kernighan and D. M. Ritchie, the C Programming Language, PHI.
2. Y. Kanetkar, Let Us C, BPB Publications.
3. E. Balagurusamy, Programming in ANSI C, McGraw-Hill.

CS102	Digital Logic and Circuits	L	T	P
		4	0	2

Number System: Weighted and Unweighted Codes, Binary, Octal, and Hexadecimal numbers; Fixed and Floating Point Number Representations, number base conversion, Complements, Binary Arithmetic: Addition, Subtraction, Multiplication and Division, BCD Code.

Boolean algebra and Logic Gates: Introduction to Boolean algebra, laws of Boolean algebra, logic gates, universal logic gates, POS and SOP notations, Canonical logic forms, Logic families.

Simplification of Boolean Functions: Laws of Boolean algebra and K-Maps, Tabulation Method.

Combinational Circuits: Design Procedure of Combinational Circuits, Adders, Subtractors, Code Converters, Magnitude Comparator, Encoder, Decoder, Multiplexer, Demultiplexer, ROM, PLAs, PALs.

Sequential Circuits: Flip-Flops: SR, D, JK, T, Master/Slave F/F, Edge-trigerred F/F, Excitation Tables; Registers, Counters: synchronous and asynchronous, Design of Counters, Shift Registers, RAM.

Suggested Readings:

1. M. M. Mano, Digital Logic and Computer Design, PHI.
2. M. M. Mano and C. R. Kime, Logic and Computer Design Fundamentals," Pearson.
3. A. Malvino, D. Leach, Digital Principles and Applications, McGraw-Hill
4. T. C. Bartee, Digital Computer Fundamentals, McGraw-Hill.

CS103	Numerical Computing	L	T	P
		4	0	2

Errors in Computer Arithmetic, Normalization.

Bisection, False position and Newton-Raphson methods for solution of nonlinear equations.

Errors in the solutions, Convergence of Solutions.

Gauss, Gauss-Siedel and Iterative methods for system of linear equations. Ill conditioned system, Pivotal Condensation, Matrix Inversion, Eigen-values, Eigen-vector, Diagonalization of Real Symmetric Matrix by Jacobi's Method.

Introduction to Finite Differences.

Polynomial Interpolation using Newton's and Lagrange's formulae.

Numerical Differentiation: Numerical Integration: Trapezoidal Rule, Simpson's Rule, Weddle's Rule, Gauss Quadrature Formula. Error in numerical Integration.

Numerical Solution of differential Equations: Picards Method, Taylor's Series Method, Euler's Method, Modified Euler's Method, Runge-Kutta Method, Predictor-Corrector Method.

Note: The Emphasis of the course is on computational implementation of the methods.

Suggested Readings:

1. V. Rajaraman, Computer Oriented Numerical Methods, PHI.
2. F. Acton, Numerical Methods that Work, Harper and Row.
3. S. D. Conte and C.D.Boor, Elementary Numerical Analysis, McGraw Hill.
4. S. S. Sastry, Introductory Methods of Numerical Analysis, PHI.
5. C. F. Gerald and P.O. Wheatley, Applied Numerical Analysis, Addison Wesley.

CS104	Computer Organization and Architecture	L	T	P
		4	0	2

Basic Organization: Stored Program Concept, Components of a Computer System, Machine Instruction, Opcodes and Operands, Instruction Cycle, Organization of Central Processing Unit: ALU, Hardwired & Micro programmed Control Unit, General Purpose and Special Purpose Registers.

Functioning of CPU: Instruction Formats, Op Codes, Instruction Types, Addressing Modes, Common Microprocessor Instructions, Multi-core Architecture, Multiprocessor and Multicomputer.

Memory Organization: Memory Hierarchy, Cache Memory, Main Memory (DRAM and ROM),Secondary Memory, Virtual Memory, Characteristics of different types of Memory.

I/O Organization: Peripheral devices, I/O interface, Modes of Transfer, Priority Interrupt, Direct Memory Access, Input-Output Processor, and Serial Communication. I/O Controllers, Asynchronous data transfer, Strobe Control, Handshaking.

Suggested Readings:

1. M. M. Mano, Computer System Architecture, PHI.
2. V. Rajaraman, T. Radhakrishnan, An Introduction to Digital Computer Design, PHI.
3. W Stallings, Computer Organization and Architecture: Designing For Performance, Prentice Hall.

CS105	Discrete Mathematics	L	T	P
		3	1	0

Sets, Relations & Functions: Property of binary relations, equivalence, compatibility, partial ordering relations, Hasse diagram, functions, inverse functions, composition of functions, recursive functions.

Mathematical Logic: Logic operators, Truth tables, Theory of inference and deduction, mathematical calculus, predicate calculus, predicates and quantifiers.

Boolean Algebra: Truth values and truth tables, the algebra of propositional functions, Boolean algebra of truth values.

Combinatorics & Recurrence Relations: Permutation, Combination, Principle of Inclusion and Exclusion, Recurrence Relations, Generating Functions.

Graph theory: Basic Concepts of Graphs and Trees, Adjacency and Incidence Matrices, Spanning Tree, Transitive Closure, Shortest Path, Planar Graphs, Graph Coloring, Eularian and Hamiltonian graphs, Applications of Graph Theoretic Concepts to Computer Science Introduction to Grammar and Languages, Regular Expression, Machines Recognizing languages: Finite State Automata: Deterministic and non-deterministic.

Suggested Readings:

1. J. P. Trembley and R. P. Manohar, Discrete Mathematical Structures with Applications to Computer Science, McGraw Hill.
2. N. Deo, Graph Theory with Applications to Engineering and Computer Science, PHI.
3. C. L. Liu, Elements of Discrete Mathematics, McGraw-Hill.
4. K. Rosen, Discrete Mathematics, Tata McGraw Hill.
5. K. L. P. Mishra, N. Chandrasekaran, Theory of Computer Science: Automata, Languages and Computation, PHI.

CS106	Operating System Concepts	L	T	P
		3	1	0

Introduction: Definition, Design Goals, Evolution; Batch processing, Multi-programming, Timesharing; Structure and Functions of Operating System.

Process Management: Process states, State Transitions, Process Control Structure, Context Switching, Process Scheduling, Threads.

Memory Management: Address Binding, Dynamic Loading and Linking Concepts, Logical and Physical Addresses, Contiguous Allocation, Fragmentation, Paging, Segmentation, Combined Systems, Virtual Memory, Demand Paging, Page fault, Page replacement algorithms, Global Vs Local Allocation, Thrashing, Working Set Model, Paging.

Concurrent Processes: Process Interaction, Shared Data and Critical Section, Mutual Exclusion, Busy form of waiting, Lock and unlock primitives, Synchronization, Classical Problems of Synchronization, Semaphores, Monitors, Conditional Critical Regions, System Deadlock, Wait for Graph, Deadlock Handling Techniques: Prevention, Avoidance, Detection and Recovery.

File and Secondary Storage Management: File Attributes, File Types, File Access Methods, Directory Structure, Allocation Methods, Free Space management; Disk Structure, Logical and Physical View, Disk Head Scheduling.

Suggested Readings:

1. A. Silberschatz, P. B. Galvin, G. Gagne, Operating System Concepts, Addison Wesley.
2. W. Stalling, Operating Systems: Internals and Design Principles, PHI.
3. A. S. Tanenbaum, Modern operating Systems, PHI.

CS107	Database Management Systems	L	T	P
		4	0	2

Introduction: Database Systems, View of Data Models, Database Languages, DBMS Architecture, Database Users and Data Independence.

ER Modeling: relation types, role and Structural Constraints, Extended ER Modeling Features, Design of an ER Database Schema, Reduction of ER Schema to Tables.

Relational Model: Relational Model Concepts, Relational Algebra.

Introduction to SQL: SQL data types and literals, Types of SQL commands, SQL operators, Tables, views and indexes, Queries and sub queries, Aggregate functions.

Relational Database Design: Functional and multi-valued Dependencies, Desirable Properties of Decomposition, Normalization up to 3 NF and BCNF.

Selected Database Issues: Security, Transaction Management, Introduction to Query Processing and Query Optimization, Concurrency Control, and Recovery Techniques.

Suggested Readings:

1. C. J. Date, An Introduction to Database Systems, Vol I & II, Addison Wesley.
2. A. Silberschatz, H. F. Korth, S. Sudarshan, Data Base System Concepts, McGraw Hill.
3. J. D. Ullman, Principles of Database Systems, Galgotia.
4. R. Elmasri, S. B. Navathe, Fundamentals of Database Systems, Pearson Education Asia.
5. R. Ramakrishnan, Database Management Systems, McGraw-Hill Education.

CS108	Data Structures and Algorithms	L	T	P
		4	0	2

Defining a Data Structure: Notion of DFA triplet, Types of Data Structures.

Linear Structures: Array, List, Stack, Queue, Applications of arrays, lists, stacks and queues.

Non-Linear Data Structures: Tree, Tree Traversals, Binary Tree, Applications of Trees, Binary Search Tree, Graph, Shortest Path, Spanning Tree, Hashing and Collision Resolution Techniques.

Introduction to Algorithm Analysis and Design: Time Complexity Analysis**,** Asymptotic Notations, Introduction to Design Techniques such as Greedy, Divide and Conquer, Dynamic Programming, Backtracking, Branch and Bound.

Searching and Sorting: Linear Search, Binary Search, Bubble Sort, Selection Sort, Insertion Sort and Quick Sort.

Suggested Readings:

1. E. Horowitz, S. Sahani, S. Anderson-Freed, Fundamentals of Data Structures in C, Universities Press.
2. Standish, Data Structure, Addison-Wesley.
3. A. M. Tennenbaum, Y. Langsam and M. J. Augenstein, Data Structures using C, PHI.
4. D. E. Knuth, The Art of Computer Programming (Volume I), Pearson.
5. N. Wirth, Algorithms+Data Structures= Program, Prentice Hall.
6. T. H. Cormen et al., Introduction to Algorithms, PHI.

CS109	Data Communication	L	T	P
		3	1	0

Introduction: Data Communications- Components, Data Representation, Data flow, Networks, Network Types, Internet History, Protocol and Standards. Networks Models: Protocol Layering, TCP/IP Protocol suite, The OSI model, Addressing.

Physical Layer: Data and Signals, Analog Signals, Digital Signals, Transmission Impairment, Data Rate limits, Performance. Digital Transmission: Digital to digital conversion, Analog to digital conversion, Transmission Modes. Analog Transmission: Digital to Analog conversion, Analog to analog conversion. Bandwidth Utilization: Multiplexing. Transmission Media: Guided media, Unguided media. Switching: Circuit Switched network, Datagram Network, Virtual Circuit Network.

Data Link Layer: Error Detection and Correction: Introduction, Block coding, Linear block codes, Cyclic codes, Checksum, Forward error correction. Data link control- Framing, Flow

and Error Control, Protocols: Simplest, Stop-and-wait, Go-back-N, Selective Repeat, Piggybacking, HDLC, Point-to-Point protocol. Multiple Access: Random Access- ALOHA, CSMA, CSMA/CD, CSMA/CA. Controlled Access- Reservation, Polling, Token Passing. Channelization- FDMA, TDMA, CDMA.

Wired LANs: Ethernet: IEEE Standards, Standard Ethernet, Bridged Ethernet, Switched Ethernet, Full Duplex Ethernet, Fast Ethernet, Gigabit Ethernet.

Wireless LANs: IEEE802.11 Standard, Bluetooth. Connecting LANs, Backbone Networks and Virtual LANs.

Suggested Readings:

1. B. A. Forouzan: Data Communications and Networking, Fourth edition, TMH.
2. A. S. Tanenbaum, Computer Networks, Fourth edition, PHI.
3. D. E. Comer, Computer Networks and Internets, Pearson.
4. W. Stallings, Data and Computer Communications, Pearson.

CS110	System Analysis and Design	L	T	P
		3	1	0

Introduction to Software System: Software crisis, Software Characteristics, Development lifecycle, Specification, Analysis, Design, Implementation and Testing.

Modular top-down analysis, design and testing, Project Feasibility, System Requirements Analysis, Fact Finding Techniques, Data Flow Diagram, Data Dictionary, Decision Tree, Decision Tables, Structured English, Systems Proposal.

System Design, CASE tools for system analysis and design, data modeling and process modeling (data flow diagrams, entity relationship diagrams), traditional and prototyping approaches, Object-Oriented Analysis and Modeling, design and development of relational database systems.

I/O design, input validation and user interface design (GUI).

Suggested Readings:

1. E. M. Awad, Systems Analysis and Design, McGraw-Hill Professional.
2. J. L. Whitten, Lonnie D. Bentley and Kevin C. Dittman, Systems Analysis and DesignMethods, McGraw-Hill.
3. K. E. Kendall, Systems Analysis and Design, Pearson Education.
4. V. Rajaraman, “System Analysis and Design”, Prentice Hall.
5. J. A. Sern, “Analysis & Design of Information System”, McGraw Hill.

CS111	Computer Organization and Operating System	L	T	P
		3	1	0

Basic Organization: Stored Program Concept, Components of a Computer System, Machine Instruction, Opcodes and Operands, Instruction Cycle, Organization of Central Processing Unit: ALU, Hardwired & Micro programmed Control Unit, General Purpose and Special Purpose Registers.

Functioning of CPU: Instruction Formats, Op Codes, Instruction Types, Addressing Modes, Common Microprocessor Instructions, Multi-core Architecture, Multiprocessor and Multicomputer.

Operating System Overview: Definition, Design Goals, Evolution; Batch processing, Multi-programming, Timesharing; Structure and Functions of Operating System, Process Management, Principals of Deadlock.

Memory and I/O Management: Memory Hierarchy, Cache Memory, Main Memory (DRAM and ROM), Secondary Memory, Virtual Memory, Input Output System, Disk Management.

Suggested Readings:

1. M. M. Mano, Computer System Architecture, PHI.
2. V. Rajaraman, T. Radhakrishnan, An Introduction to Digital Computer Design, PHI.
3. W. Stallings, Computer Organization and Architecture: Designing For Performance,Prentice Hall.
4. A. Silberschatz, P. B. Galvin, G. Gagne, Operating System Concepts, Addison Wesley.
5. W. Stalling, Operating Systems: Internals and Design Principles, PHI.
6. A. S. Tanenbaum, Modern operating Systems, PHI.

CS112	Mathematical Foundations of Computer Science	L	T	P
		3	1	0

Sets, Relations & Functions: Set, set operations, relation, matrix and graph representation of relation, Properties of binary relation, composition of relations, Equivalence, Compatibility, and Partial order relations. Hasse diagram, Partial order set (POSET), lattice, properties of lattice, complete and bounded lattice. Complement of an element in lattice, complemented lattice, and Boolean algebra. Function, number theoretic function, and recursion.

Mathematical Logic: Propositional calculus / statement calculus – statement, logic connective, statement formula and truth table, well formed formula, tautology, contradiction, substitution instance, equivalence of formula, duality law, tautological implication, functionally complete set of connectives, satisfiability, decision problem, normal forms. Theory of inference for propositional calculus. Predicate calculus: Limitation of propositional calculus, statement representation using predicate and quantifier,

universe of discourse, rules for well formed formula for predicate calculus, free and bounded variable, scope of quantifier, precedence of quantifier and logical connective, logical equivalences of quantifier, negation of quantified statement, Theory of inference for predicate calculus.

Probability, Distributions, Estimation and Hypothesis Testing: Random phenomenon, probability, conditional probability, statistical independence, random variable. Commonly used univariate and multivariate distributions functions. Joint and marginal distribution. Moment, expectation, and moment generating function. Central limit theorem and laws of large numbers. Some important random sample generation procedure, sampling distributions. Theory of Estimation: Sufficient statistics, completeness, unbiased estimation, moment estimation, maximum likelihood estimation, notion of admissibility of estimators. Testing of Statistical Hypothesis: Generalized NP lemma, Unbiased critical regions, unbiased tests and similar regions, invariant test, testing and confidence regions. Model Building: Regression analysis, model selection, least square methods and application. Bayesian Paradigm: Introduction, Bayesian and Minimax decision rules, selection of a prior, Bayesian point estimation, Bayesian sufficiency, and Classical approximation methods. Random Processes: Introduction to random processes, Gaussian processes, Markov processes, stochastic processes, and stationary processes. Poisson process, birth process, death process, Markov chains. Finite-state Markov chains, Queuing system.

Combinatorics & Recurrence Relations: Permutation, Combination, Principle of Inclusion and Exclusion, Recurrence Relations, Generating Functions.

Graph theory: Basic Concepts of Graphs and Trees, Adjacency and Incidence Matrices, Spanning Tree, Transitive Closure, Shortest Path, Planar Graphs, Graph Coloring, Eularian and Hamiltonian graphs, Applications of Graph Theoretic Concepts to Computer Science, Introduction to Grammar and Languages, Regular Expression, Machines Recognizing languages: Finite State Automata: Deterministic and non-deterministic

Suggested Readings:

1. J. P. Trembley and R. P. Manohar, Discrete Mathematical Structures with Applications to Computer Science, McGraw Hill Education, 2017.
2. C. L. Liu, D. Mohapatra, Elements of Discrete Mathematics: A Computer Oriented Approach, McGraw Hill Education, 2017.
3. K. Rosen, Discrete Mathematics and Its Application, McGraw Hill Education,2017.
4. P. Linz, An Introduction to Formal Languages and Automata, Jones & Bartlett,2016.
5. K. L. P. Mishra, N. Chandrasekaran, Theory of Computer Science: Automata, Languages and Computation, PHI, 2006.
6. N. Deo, Graph Theory with Applications to Engineering and Computer Science,PHI, 1979.
7. V. K. Rohatgi, A. K. Md. Ehsanes Saleh, An introduction to probability and statistics, Wiley Eastern, New Delhi, 2008.

8. I. Miller, M. Miller, Mathematical Statics with Applications, PHI, 1998.
9. A. Papoulis, Probability and Statistics, Pearson, 1989.
10. M. Mitzenmacher, E. Upfal, Probability and Computing: Randomized Algorithms and Probabilistic Analysis, Cambridge University Press, 2005.
11. H. Stark, J. Wood, Probability and random processes with application to signal processing, Pearson, 2012.
12. A. M. Mathai, Lecture module 6, CMS pala, 2009.
13. C. R. Rao, Linear Statistical Inference and its Applications (2nd Ed.), Wiley Interscience, 2001.
14. J. Medhi, Stochastic Processes, New Age International, 2019.

CS201	Probability and Statistics for Computer Science	L	T	P
		3	1	0

Introduction: Data Collection and Descriptive Statistics, Inferential Statistics and probability Models, Population and Samples.

Descriptive Statistics: Describing Datasets, Single Point Summarization, Paired Datasets.

Probability: Sample Space and Events, Axioms of Probability, Conditional Probability.

Random Variables and Expectations: Random variables, Jointly Distributed Random variables, Expectation, Variance, Co-variance, Probability Distributions. Parameter Estimation-Maximum Likelihood Estimates; Regression Analysis; Applications, Markov Process, Poisson Process.

Suggested Readings:

1. S. M. Ross, Introduction to Probability and Statistics for Engineers and Scientists, Elsevier.
2. W. Feller, An Introduction to probability Theory and its Applications- Vol. 1, Wiley.
3. K. S. Trivedi, Probability and Statistics with Reliability, Queuing and Computer Science Applications, Wiley.

CS202	Theory of Computation	L	T	P
		3	0	0

Formal Language and Grammar: Production systems, Chomsky Hierarchy, Right linear grammar and Finite state automata, Context free grammars, Normal forms, Derivation trees and ambiguity.

Finite state Automata: Non deterministic and deterministic FSA, NFSA with ε- moves, Regular Expressions, Equivalence of regular expression and FSA, Pumping lemma, closure properties and decidability, Myhill - Nerode theorem and minimization, Finite automata with output.

Pushdown automata: Acceptance by empty store and final state, Equivalence between pushdown automata and context-free grammars, Closure properties of CFL, Deterministic pushdown automata.

Turing Machines: Techniques for Turing machine construction, Generalized and restricted versions equivalent to the basic model, Godel numbering, Universal Turing Machine, Recursively enumerable sets and recursive sets, Computable functions, time space complexity measures, context sensitive languages and linear bound automata.

Decidability: Post's correspondence problem, Rice's theorem, decidability of membership, emptiness and equivalence problems of languages.

Suggested Readings:

1. J. E. Hopcraft, R. Motwani, J. D. Ullman, Introduction to Automata Theory, Languages and Computation, Pearson.
2. H. R. Lewis, C. H. Papadimitrou, Elements of the Theory of Computation, PHI.
3. P. Linz, An Introduction to Formal Language and Automata, Narosa Publisher.
4. K. L. P. Mishra, N. Chandrasekaran, Theory of Computer Science: Automata, Languages and Computation, PHI.

CS203	Design and Analysis of Algorithms	L	T	P
		3	0	1

Introduction to Algorithms: Time and space complexity, average and worst-case analysis, asymptotic notation, recurrence equations and their solution.

Algorithmic Techniques: Search techniques (backtracking and bounding), Search Trees, Sorting algorithms – heapsort, quick sort, sorting in linear time (counting sort, radix sort, bucket sort), Greedy algorithms (Activity-selection problem, Huffman coding, knapsack, shortest path and minimum spanning tree in graphs), Divide and conquer – Merge Sort, Integer Multiplication, Solving Recurrence-substitution method and recursion-tree, master theorem; Dynamic programming (0/1 knapsack, Traveling salesman problem, matrix multiplication, all-pairs shortest paths, longest common subsequence, optimal binary search trees).

Computational complexity: Problem classes: P, NP, NP-complete, NP-hard. Reduction. Examples of NP-complete problems.

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, 2006.
5. E. Horowitz, S. Sahni, S. Rajasekaran, Fundamentals of Computer Algorithms, Galgotia.

CS204	Object Oriented Programming	L	T	P
		3	0	2

Object Oriented Concepts: Objects and Classes, Bottom-up approach, O-O design principles, O-O Design and Modeling.

Basic O-O language Constructs: Primitive Data Types and Operations, Selection Statements, Loops, Arrays, Strings, Objects and Classes, Inheritance and method overriding, Polymorphism.

Java Language Fundamentals: Object Design: constructors, instance variables, methods. Memory models, scope, streams and I/O programming, Inner classes, Interfaces and packages, Exception Handling, Multithreading.

Advanced Concepts: Creating GUIs and Displaying Data, Event Driven Programming.

Frameworks: The framework concept, Frameworks in the Java API: Collections Framework, Graphics Framework

Suggested Readings:

1. C. T. Wu, An introduction to Object Oriented Programming with JAVA, McGraw Hill.
2. E. Balagurusamy, Programming with Java, TMH.
3. B. Eckel, Thinking in Java, Pearson.
4. H. Schildt, Java: The Complete Reference, McGraw Hill Education
5. H. Deitel, P. Deitel, Java 9 for Programmers, Pearson

CS205	Software Engineering	L	T	P
		3	0	0

Introduction to Software Engineering: Definition, Software development and life-cycle models, CMM, Software Quality, role of metrics and measurement.

Requirements Analysis and Specification: SRS Building Process, Specification Languages, Validation of SRS, metrics, monitoring and control, Object Oriented analysis.

Software Project Planning: Software Cost Estimation Techniques, Project Scheduling & Tracking, Project Team Standards, software configuration management.

Software Architecture: Role of Software Architecture, Architecture Views, Component and Connector View, Architecture Styles for C&C View, Architecture Evaluation.

Software Design and Implementation: Design Concepts and Notations, Functional & Object Oriented Design Concepts, Design Strategies, Design specification and verification, Metrics, Design Translation Process.

Software Testing and Reliability: Strategies & Techniques, Debugging, Software Maintenance, Software Reliability and Availability Models, Software Reengineering, Cleanroom Approach, Software Reuse. Introduction to IEEE Standards, Case Studies.

Suggested Readings:

1. P. Jalote, An Integrated Approach to Software Engineering, IIIrd Edition, Narosa Publishing House.
2. R. S. Pressman, Software Engineering: A Practitioner's approach, McGraw-Hill.
3. I. Sommerville, Software Engineering: Pearson Education.
4. C. Ghezzi, M. Jazayeri, D. Mandrioli, Fundamentals of Software Engineering, PHI.
5. R. Mall, Fundamentals of Software Engineering, PHI.

CS206	Computer Networks	L	T	P
		3	1	0

Introduction to Internetworking and TCP/IP.

Addressing and Routing: Logical Addressing- IPv4 Addresses, IPv6 Addresses. Internet protocol- Internetworking, IPv4, IPv6, transition from IPv4 to IPv6. Address Mapping- ARP, RARP, BOOTP, DHCP, Error Reporting- ICMP. Multicasting-IGMP. Routing- Delivery, Forwarding, Intra and Inter-domain routing, Unicast Routing Protocols-Distance Vector Routing, Link State Routing, Path Vector Routing. Multicast Routing protocols.

TCP and UDP: Process to process delivery- Client/Server Paradigm, Multiplexing and De-multiplexing, Connectionless Versus Connection-Oriented Service, Reliable Versus Unreliable. UDP- Well-Known Ports for UDP, User Datagram, UDP Operation, Use of UDP.TCP- TCP Services, TCP Features, Segment, A TCP Connection, Flow Control, Error Control. Congestion Control- Network performance, Open loop congestion control, Closed loop congestion control, Congestion control in TCP, Quality of Service.

Network Applications: DNS- Name space, Distribution of name space, DNS in the Internet, resolution, DDNS. Remote logging- TELNET, Electronic Mail- SMTP, POP, IMAP, File Transfer- FTP, WWW, HTTP, Network Management: SNMP .

Network Security: Security services- message confidentiality, message integrity, Message authentication, Digital signature, Entity authentication, Key management- Symmetric, Asymmetric. Security in the Internet: IPSec, TLS, PGP, VPN and Firewalls.

Suggested Readings:

1. B. A. Forouzan, Data Communications and Networking, Fifth edition, TMH .
2. A. S. Tanenbaum, Computer Networks, Fourth edition, PHI.
3. A. Forouzan, TCP/IP Protocol Suite, 4th Edition, McGraw Hill, 2010
4. D E. Comer, Internetworking with TCP/IP Principles, Protocols and Architecture, Pearson Education.

CS207	Compiler Design	L	T	P
		3	1	0

Introduction: Translators, Various phases of compiler, tool based approach to compiler construction.

Lexical analysis: token, lexeme and patterns, difficulties in lexical analysis, error reporting, implementation, regular definition, transition diagrams, LEX.

Syntax Analysis: top down parsing (recursive descent parsing, predictive parsing), operator precedence parsing, bottom-up parsing (SLR, LALR, Canonical LR), YACC.

Syntax directed definitions: inherited and synthesized attributes, dependency graph, evaluation order, bottom-up and top-down evaluation of attributes, L-attributed and S-attributed Definitions.

Type checking: type system, type expressions, structural and name equivalence of types, type conversion, overloaded functions and operators, polymorphic functions.

Run time system: storage organization, activation tree, activation record, parameter passing, dynamic storage allocation, symbol table: hashing, linked list, tree structures.

Intermediate code generation: intermediate representation, translation of declarations, assignments, control flow, Boolean expressions and procedure calls, implementation issues.

Code generation and Optimization: issues, basic blocks and flow graphs, register allocation, code generation, dag representation of programs, code generation from DAGs, peephole optimization.

Suggested Readings:

1. A. V. Aho, J. D. Ullman, Principles of Compiler Design, Narosa Publishing House.
2. J. P. Trembley, P. G. Sorensen, The Theory and Practice of Compiler Writing, McGraw Hill.
3. A. Holub, Compiler Design in C, PHI

CS208	Artificial Intelligence	L	T	P
		3	1	0

Introduction: Definitions and Approaches, History of AI, Philosophical Foundations of AI, Turing's Test, Searle's Chinese Room, Symbolic and Connectionist AI, Concept of Intelligent Agents.

AI Problem Solving: Problem solving as state space search, production system, control strategies and problem characteristics; Search techniques: Breadth First and Depth-first, Hill-climbing, Heuristics, Best-First Search, A* algorithm, Problem reduction and AO* algorithm, Constraints satisfaction, Means Ends Analysis, Game Playing.

Knowledge Representation and Reasoning: Predicate and prepositional logic, Resolution, Unification, Deduction and theorem proving, Question answering; Forward versus backward reasoning, Matching, Indexing, Semantic Net, Frames, Conceptual Dependencies and Scripts.

Applications: Introduction to Natural Language Processing, Expert System.

Suggested Readings:

1. S. Russel, P. Norvig, Artificial Intelligence: A Modern Approach, Pearson.
2. E. Rich, K. Knight, Artificial Intelligence, Tata McGraw Hill.
3. N. J. Nilsson, Artificial Intelligence: A New Synthesis, Morgan Kaufmann.

CS209	Machine Learning	L	T	P
		3	0	2

Machine Learning Concepts: Designing a Learning System, Styles of Learning; Supervised learning; Unsupervised Learning; Semi-Supervised Learning; Basics of Decision Theory, Information Theory and Probability Distributions; Linear and Logistic Regression.

Bayesian Learning: Notion of Prior, Likelihood and Posterior; Naïve Bayes and Conditional Independence; Estimation using Maximum Likelihood; Hidden variables and Missing Data; Bayesian Models.

Classification & Clustering: Naive Bayes, Nearest Neighbour and Linear Classification Models; K-means and Expectation Maximization for Clustering; Mixture Models, Flat and Hierarchical Clustering, Applications of Classification and Clustering.

Suggested Readings:

1. T. M. Mitchell, Machine Learning, McGraw Hill.
2. C. M. Bishop, Pattern Recognition and Machine Learning, Springer.
3. K. P. Murphy, Machine Learning: A Probabilistic Perspective, MIT Press.

4. D. Barber, B. Reasoning, Machine Learning, CUP.
5. P. Harrington, Machine Learning in Action, Manning Publications.

CS210	Advanced Course in Data Structures and Algorithms	L	T	P
		2	2	0

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.

CS211	Mathematical Foundations of Computing	L	T	P
		2	1	0

Calculus and Transformation: Basic Calculus, Differential and Integral Equations, and Concept of Linear Transformation, and Matrix Theory, Basic Transform and Their Application: Laplace Transform, Fourier series and Fourier Transform, Wavelet Transform, and Z-transform, recurrence relation and solution.

Probability, Statistics and Random Process: Probability Theory: Random Phenomenon, Probability, Conditional Probability, Statistical Independence, Random Variable, Distribution function, Expectation, Commonly used Distributions, Moment and moment generating function, Multivariate distribution, Joint and Marginal Distribution, and Laws of Large Numbers.

Statistics: Estimation – Concept of sufficiency, completeness, and unbiased property of estimator. Moment method, Maximum likelihood method, Expected maximization method for estimation. Bayes Paradigm : Concept of Bay's and Bayesian estimation.

Testing of Statistical Hypothesis- Critical region, unbiased tests and similar region, unbiased test and similar regions, invariant test, testing on parameter of distributions. Some non-parametric test.

Decision Theory- Basic Concepts, Utility and Loss, Prior information, Bayesian analysis, Concept of Minimax,

Model Building And Regression- Regression Analysis, Model Selection, Least square methods and applications. Design of Experiments and Analysis of Variance:

Random Process- Introduction to random processes, Gaussian processes, Markov processes, stochastic processes, and stationary processes. Poisson process, birth process, death process, generalized birth and death process, Gambler's Ruin Problem, Markov chains, Martingales and their properties. Finite-state Markov chains, Non-homogeneous Poisson processes, Ruin models, Martingale approach to ruin theory. Stochastic calculus, Ergodicity and duality, spectral density, Noise model for receiving system, matched filtering and signal detection, Weiner filtering and signal extraction, Random signal detection, Autoregressive models and Linear prediction.

Mathematical logic, Fuzzy Mathematics and Fuzzy Logic: Propositional logic syntax and semantics, Tautologies, axiom system and deduction, Proof of soundness and completeness, First order logic syntax and semantics, Structures, models, satisfaction and validity, Axiomatization, soundness and completeness. Fuzzy versus crisp set, Operations on fuzzy set, Fuzzy Arithmetic, Fuzzy Relation, Possibility Theory, Fuzzy Logic. Applications: Pattern Recognition, Fuzzy Decision making, other applications if time permits.

Suggested Reading:

1. T. M. Apostol, One-variable calculus with an introduction to linear algebra-Vol. 1, Wiley India, 2007.
2. T. M. Apostol: Multi-variable calculus and linear algebra with applications to differential equations and probability, Wiley India, 2007.
3. A. M. Mathai, Lecture module 5, 6,7 CMS pala, 2009.
4. I. Miller, M. Miller, Mathematical Statics with Applications, PHI.
5. A. Papoulis, Probability and Statistics, Prentice Hall International.

6. S. M. Kay, Fundamentals of Statistical Signal Processing : Estimation Theory, PTR Prentice Hall, Englewood Cliffs, New Jersey.
7. S. M. Kay, Fundamentals of Statistical Signal Processing : Detection Theory, PTR Prentice Hall, Englewood Cliffs, New Jersey.
8. R. M. Smullyan, First Order Logic, Dover Press, 1995.
9. Gerorge J. Klir and Bo Yuan, Fuzzy Sets And Fuzzy Logic Theory and Applications, Printice – Hall of India Private Limited, 2002.
10. E. L. Lehmann, Theory of Point estimation, 2nd edition, Springer, 1998.
11. E. L. Lehmann, Testing Statistical Hypotheses, J. Wiley & Sons, NY, 1986.
12. J. G. Proakis, D. G. Manolakis, Digital Signal Processing - Principles, Algorithms and Application, 3rd edition, Pearson Education, 2004.
13. J. Medhi, Stochastic Processes, New Age Science Ltd; 3rd Revised edition edition (31 December 2009)
14. D. C. Montgomery, E. A. Peck, G. G. Vining, Introduction to Linear Regression Analysis, Wiley India.

CS311	Data Mining	L	T	P
		2	1	1

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
		2	1	1

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
		2	1	1

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
		2	1	1

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
		2	1	1

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
		2	1	1

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
		2	1	1

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
		2	1	1

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
		2	1	1

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
		2	1	1

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
		2	1	1

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
		2	1	1

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
		2	1	1

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
		2	1	1

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
		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
		2	1	1

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
		2	1	1

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
		2	1	1

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
		2	1	1

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
		2	1	1

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
		2	1	1

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
		2	1	1

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
		2	1	1

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
		2	1	1

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
		2	1	1

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
		2	1	1

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
		2	1	1

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.

CS401	Communication Skills	L	T	P
		1	0	1

This course is designed to help students improve their communication skills. Students will be trained through activities such as Group Discussion, Presentation, Interviews etc.

CS402	Technical Writing & Seminar	L	T	P
		1	0	1

This course is designed to teach students about writing a good technical report or a scholarly paper. Students will be required to understand how to structure technical reports and prepare a report or review paper on a topic approved by the department.

CS 403/ CS404/ CS405	Reading Elective A/B/C	C
		2

This is a self-study course. Students will have to choose one Reading Elective from a list to be prepared by the department on an annual basis. They will study and complete the course on their own and then present themselves for evaluation at the end of the semester. Students will be encouraged to complete and obtain certificate of online courses from popular E-learning portals like Coursera, Udacity, MIT Open Course Ware, NPTEL etc. as part of the reading elective course.

CS406	Comprehensive Viva	C
		2

This course involves examination of learning outcome of students through a Viva Voce from the entire syllabus covered in their program.

CS407	Introduction to Information Technology	L	T	P
		2	0	0

Concepts of Data and Information, Data Processing, Components of a Computer System, Computer Networks, LAN and WAN, Internet, World Wide Web, Search Engine, Concept of E-mail, File Transfer over Internet, Computer viruses. Application of ICT in day to day life: Education, Business, Health.

Suggested Readings:

1. V. Rajaraman, Fundamentals of Computers, PHI.
2. R. Fox, Information Technology, Chapman and Hall/CRC.

CS408	Fundamentals of Computing	L	T	P
		2	0	0

Characteristics of Computers, Evolution of Computing, Binary Number Systems, Types of Computer Software, Operating Systems, Programming Languages, Problem Solving Techniques using Computers: Algorithm, Flow Charts, Pseudo code. Introduction to

Computer Networks, Internet, World Wide Web, Getting Connected to Internet, Use of Internet for Scholarly Purposes.

Suggested Readings:

1. E. Balagurusamy, Computing Fundamentals & C programming, TMH.
2. A. P. Godse, D. A. Godse: Fundamental of Computing and Programming (Technical Publications).

CS501	Minor Project	C
		3

This course is first hands on course for Masters students. The students will carry out literature survey in a selected area, prepare a review paper and a working prototype of a computational system or initial analysis/ study in a research area.

CS502	UG Project	C
		12

This is Project Work for Undergraduate Students. Students of Undergraduate program will have to work towards design of information systems using databases and Web-based user interface.

CS503	Dissertation	C
		16

This course involves computational work and thesis writing by Masters Students. The students are expected to carry out independent work on a research/ practical problem and submit a detailed report highlighting their contribution in the area chosen.

CS504	Major Project	C
		16

This course is a full-scale project involving design of a complete computational/ information system. At the end of the course, students will submit a detailed project report describing the problem and the computational solution developed for it.

CS505	Industrial Training	C
		16

This course involves full-time industrial training in a govt/ private organization involved in development of hardware and software based solutions and systems.