Papers for Comprehensive PhD Examination

Department of Computer Science and Engineering

February 2023

Mapping of comprehensive courses with research areas of the department:

It is to be noted that this mapping is only suggestive and the SRC is empowered to suggest the comprehensive papers for every student depending on his/her research area and foundations.

Research Areas	**Comprehensive Papers**		
Theoretical Computer Science	Mathematical Foundations in Computer Science	Design and Analysis of Algorithms	Theory of Computation
Systems	Fundamentals of Operating System and Distributed Computing	Computer Organization and Architecture	Computer Networks and Communication
Software and Security	Database and Data Engineering	Program Analysis and Software Engineering	Security
Artificial Intelligence	Pattern Analysis and Machine Intelligence	Modern AI	Image and Vision Computing

Course Title	**Mathematical Foundations in Computer Science (MFCS)**	Number	CSECXXX C-for comprehensive
Department	CSE		
Offered for	Comprehensive Examination		

Objectives

- This paper is intended to measure the foundations to mathematical rigor that are used in most areas of Computer Science and limitations of Computation.

Contents

Combinatorics: Pigeonhole Principle, Mathematical Induction, Permutation, Combination, Binomial Theorem, Inclusion-Exclusion Principle, Recurrence **[Ref 1, Chapter 5, 6, 8]**

Graph Theory: Basics of Graph Theory, Trees, Matching & Coloring, Planar Graphs. **[Ref 1, Chapter 10,11]**

Probability: Introduction to Discrete Probability, Conditional Probability, Bayes' Theorem, Random Variables and Expectations **[Ref 3, Chapter 1-4]**

Logic, Function, and Relation: Propositional Logic, Predicates and Quantifier, Rules of Inference, Sets, Function, Relation and their properties, Equivalence Relations, Partial Ordering **[Ref 1, Chapter 1,2 and 9]**

Proof Techniques: Constructive, Contraposition, Contradiction, Mathematical Induction **[Ref 1, Chapter 1 and 4]**

Linear Algebra Matrices, Determinants, System of linear equations, Eigenvalues and eigenvectors, LU decomposition **[Ref. 2, Chapter 1-7]**

Textbook/Book Chapter

1. Kenneth Rosen (2019), Discrete Mathematics and Its Applications, 8th Edition, McGraw-Hill.
2. Gilbert Strang (2016), Linear Algebra, Wellesley-Cambridge Press
3. Sheldon Ross (2014), Introduction to Probability and Statistics for Engineers and Scientists. Academic Press.

Online Course Material

1. Discrete Mathematical Structures, https://nptel.ac.in/courses/106106094/
2. Introduction to Probability in Computing, https://nptel.ac.in/courses/106/106/106106176/
3. Linear Algebra, https://nptel.ac.in/courses/111/101/111101115/

Course Title	**Theory of Computation**	Number	CSECXXX C-for comprehensive
Department	CSE		
Offered for	Comprehensive Examination		

Objectives

- This paper is intended to evaluate the knowledge of abstract computational devices and limits of computation.

Contents

Introduction: Motivation for studying theory of computation, a quick overview of the subject. Notion of formal language. Language membership problem, why this is taken as the central problem of the subject. **[Book 1, Chapter 1]**

Finite automata and regular expressions: DFA, NFA (with and without transitions), their equivalence. Proof that for some languages NFAs can be exponentially more succinct than DFAs. Definition of regular expressions. Proof that FAs recognize, and regular expressions denote the same class of languages, viz., regular languages. **[Book 1, Chapter 2,3]**

Properties of regular languages: Pumping lemma and its use to prove non-regularity of a language, closure properties of class of regular languages, decision properties: convert- ing among representations, testing emptiness, etc. Minimization of DFAs. **[Book 1, Chapter 4]**

Context-free grammars and languages: Derivation, parse trees. Language generated by a CFG. Eliminating useless symbols, -productions, unit productions. Chomsky normal form. **[Book 1, Chapter 5]**

Pushdown automata: Definition, instantaneous description as a snapshot of PDA com- putation, notion of acceptance for PDAs: acceptance by nal states, and by empty stack; the equivalence of the two notions. Proof that CFGs generate the same class of languages that PDAs accept. **[Book 1, Chapter 6]**

Properties of context-free languages: Pumping lemma for context-free languages and its use to prove a language to be not context-free. Closure properties of the class of context- free languages. CYK algorithm for CFL membership, testing emptiness of CFLs. **[Book 1, Chapter 7]**

Turing machines: Historical context, informal proofs of undecidability. Definition of TM, instantaneous description as a snapshot of TM computation, notion of acceptance. Robustness of the model: both natural generalizations and restrictions keep the class of languages accepted invariant. (Generalizations: multi-track, multi-tape, nondeterministic, etc. Restrictions: semi-infinite tape, counter machines). Church-Turing hypothesis. **[Book 1, Chapter 8]**

Undecidability: Definitions of r.e. and recursive languages. Turing machine codes, the diagonalization language and proof that it is not r.e. Universal Turing machine. Universal language, its semi-decidability. Reducibility and its use in proving undecidability. Rices theorem. Undecidability of Posts correspondence problem. **[Book 1, Chapter 9]**

Intractability: Motivation for the notion. The class P as consensus class of tractable sets. Classes NP, co-NP. Polynomial time reductions. NP-completeness, NP-hardness. Some NP-completeness proofs: vertex cover, clique, independent sets, Hamiltonian graphs, subset-sum, set cover. **[Book 1, Chapter 10]**

Textbook/Book Chapter

1. J. Ullman and J. Hopcroft (2006), Introduction to Automata Theory, Languages, and Computation, Pearson Education

Online Course Material

1. https://www.youtube.com/watch?v=al4AK6ruRek&list=PLbMVogVj5nJSd25WnSU144ZyGmsqjuKr3&ab_channel=nptelhrd

Course Title	**Design and Analysis of Algorithms**	Number	CSECXXX C-for comprehensive
Department	CSE		
Offered for	Comprehensive Examination		

Objectives

- This paper is intended to measure the knowledge of basic data structures used in computer science and mathematical techniques for algorithm analysis and design.

Contents

Algorithm analysis and complexity: Big/little -Oh, Omega, Theta notation, Recurrence equations. **[Book. 2, Chapter 3]**
Abstract data types: Linear data structures, Tree, Binary trees, Tree traversal. **[Book. 2, Chapter 10]**
Search trees: Binary search trees, Balanced search trees, AVL trees, B-Trees. **[Book. 2, Chapter 12]**
Heaps: Binary Heap, Heap order property and min/max heaps. **[Book. 2, Chapter 6]**
Sets: Disjoint set ADT, Basic operations on Sets, Union/Find algorithm. **[Book. 2, Chapter 21]**
Sorting and Searching algorithms: Linear and Binary Search, Bubble sort, Selection sort, Bucket sort, Insertion sort, Quick sort, Merge sort. **[Book. 2, Chapters 2,6,7,8]**
Graph algorithms: DFS in directed and undirected graphs, BFS and connected components, Connectivity in directed graphs, Bellman Ford, Dijkstra's algorithm, topological sorting **[Book. 2, Chapter 22,24]**
Greedy techniques and Dynamic programming: Prim's, Kruskal's, interval scheduling, Matrix Multiplication, Knapsack **[Book. 2, Chapter 15, 16, 23]**

Textbook/Book Chapter

1. M. A. WEISS (2002), Data Structures and Algorithm Analysis in C, Addison-Wesley, 2nd Edition.
2. T. H. CORMEN, C. E. LEISERSON, R.L. RIVEST, C. STEIN (2009),Introduction to Algorithms, MIT Press, 3rd Edition
3. Jon Kleinberg, Eva Tardos (2005), Algorithm Design, Pearson Education, 1st Edition.

Online Course Material

https://nptel.ac.in/courses/106/102/106102064/
https://www.youtube.com/watch?v=DTuB5vlx_Kk&list=PLhkiT_RYTEU2blpB59zZtnxdR7zzsc0Dy&index=1
https://nptel.ac.in/courses/106106127

Course Title	**Database & Data Engineering**	Number	CSCxx C-for comprehensive
Department	Computer Science and Engineering		
Offered for	Comprehensive Examination		

Objectives
To test understanding of fundamentals of database management systems and data engineering.

Contents
Database System Concepts & Architectures **[Book 1, Chap. 2]**
Database Design Theory **[Book. 1, Chap. 14; Book. 2, Chap. 6-7]**
Query Processing & Query Optimization **[Book. 1, Chap. 18-19; Book. 2, Chap. 15-16]**
Transaction Processing, Concurrency Control, Database Recovery **[Bookef. 1, Chap. 20-22; Book. 2, Chap. 17-19]**
The Data Engineering Lifecycle **[Book. 3, Chap. 2]**
Data Generation in Source Systems **[Book. 3, Chap. 5]**
Data Processing Pipelines **[Book. 3, Chap. 7,8]**
Data Storage Management, Storage Hierarchy **[Book. 3, Chap. 6]**

Textbook/Book Chapter
1. R. ELMASRI, S.B. NAVATHE (2017), Fundamentals of Database Systems, Pearson Education, 7th Edition.
2. Silberschatz, A., Korth, H., Sudarshan, S., (2019), Database System Concepts, 7th Edition, McGraw Hill.
3. J. Reis, M. Housley (2022), Fundamentals of Data Engineering, O'Reilly Media, Inc.,ISBN: 9781098108304

Online Course Material
1. Lecture Notes on Database Systems (MIT): https://rb.gy/ohuzbv
2. Video Lectures on Database Systems (CMU): https://rb.gy/prjvzq

Course Title	**Program Analysis and Software Engineering**	Number	CSCxx C-for comprehensive
Department	Computer Science and Engineering		
Offered for	Comprehensive Examination		

Objectives
To test understanding of fundamentals of database management systems and software engineering.

Contents
Programming Paradigms, Structured and Object Oriented, Functional Paradigms **[Book. 2, Chap. 3, 4, 5, 6]**
Need for software engineering, Software quality attributes, Software product pipelines **[Book. 1, Chap. 1]**
Software lifecycle models and processes **[Book. 1, Chap. 2]**
Requirement engineering using UML Diagrams. **[Book. 1, Chap. 7, 8]**
Design principles, Design Patterns, Software Architecture **[Book. 2, Chap. 7-14, Book. 1 Chap. 9, 10]**
Software Testing, Verification and Validation **[Book. 1, Chap. 19, 20]**

Textbook/Book Chapter

1. R. S. PRESSMAN, B. R. MAXIM (2019), Software Engineering: A Practitioner's Approach, McGraw-Hill India, 2019, 9thEdition.
2. Robert C. Martin (2017), Clean Architecture: A Craftsman's Guide to Software Structure and Design, Pearson

Online Course Material

1. Design Patterns, University of Alberta https://in.coursera.org/learn/design-patterns
2. Engineering Practices for Building Quality Software, https://in.coursera.org/learn/engineering-practices-secure-software-quality

Course Title	**Security**	Number	CSCxx C-for comprehensive
Department	Computer Science and Engineering		
Offered for	Comprehensive Examination		

Objectives
To test understanding of fundamentals of Cryptography and security.

Contents

Cyber Security, Vulnerabilities, Safeguards: Internet governance – Challenges and constraints, Cyber threats, Cyber security, Vulnerabilities, safeguards, Access control, Authentication, Biometrics, Deception, Denial of Service Filters, Ethical hacking, Firewalls, Response, Scanning, Security policy, Threat management[**Book. 1, Chap 1**]
Cryptography: Shannon's Approach to Cryptography: Measures of security, Perfect secrecy, Definition of entropy, One-time pad , Symmetric Key Cryptography - Stream ciphers and Block ciphers, Modes of operation, Cryptographic Hash Functions, Hash functions and their security properties, Authentication, MAC Algorithm, Public Key Cryptosystems, Diffie-Hellman Key exchange, RSA and ElGamal cryptosystems, Elliptic Curve Cryptography, Digital signatures, Key Distribution and Key Agreement Protocols **[Book. 2, Chap. 1-8, Chap. 11-12]**
Network Security: TCP/IP threats, The IPSEC protocol, Network Access Control and Cloud Security, Transport-Level Security, The SSL and TLS protocols, Firewalls and Virtual Private Networks (VPNs), Wireless Network Security, Electronic mail security, Worms, DDoS attacks, BGB and security considerations, IP Security **[Book. 3, Chap. 16-20].**
Intrusion Detection and Prevention: Intrusion detection and Prevention techniques, Anti-malware software, Security information management, Network session analysis, System integrity validation **[Book. 3, Chap. 22].**

Textbook/Book Chapter
1.P.W. SINGER, A. FRIEDMAN (2014), Cybersecurity: What Everyone Needs to Know, OUP, 1st Edition.
2. Douglas R. Stinson, Maura B. Paterson (2018). Cryptography: theory and practice. 4/E Chapman and Hall/CRC
3. W. Stallings, Cryptography and Network Security, Pearson Education, India, 8th edition, 2020.

Online Course Material

Course Title	**Fundamentals of Operating System and Distributed Computing**	Number	CSCxx C-for comprehensive
Department	Computer Science and Engineering		
Offered for	Comprehensive Examination		

Objectives

- Understand the fundamentals of operating systems concepts
- Understand the concepts of distributed computing environment
- Ability to design systems that involve cooperation among multiple processing nodes

Contents

Introduction to Operating Systems and UNIX: OS design principles and structure, concepts of shell and kernel, kernel data structure, Basic UNIX commands, System Calls and Interrupts **[Book. 1 Chapter 1-2, Book. 3 Chapter 1-14]**
Process and Thread Management: Process concepts, operation, IPC, Sockets and RPC, Threads and concurrency, CPU scheduling **[Book. 1 Chapter 3-5]**
Process synchronization and deadlock: Critical Section problem**,** Peterson's solution to synchronization**,** locks**,** semaphores, monitors, classical synchronization problems, deadlock: principles, avoidance, detection and prevention techniques **[Book. 1 Chapter 6-8]**
Virtualization*:* Architectures of Virtual Machines, Types of VMs and their implementation, Virtualization and OS components **[Book. 1, Chapter 18]**
Memory management: Main memory, Virtual memory, Paging and Segmentation, Page replacement, Kernel memory management, Secondary storage management **[Book. 1, Chapter 9-11]**
File Systems and internals: File organization, Indexing, File systems, Distributed File System. **[Book. 1, Chapter 13-15, 19]**
Distributed computing paradigm: Design issues and principles, synchronous vs asynchronous execution, models of distributed computation, logical time, global state and snapshot, terminology and basic algorithms, message ordering and group communication. **[Book. 2 Chapter 1-6]**

Textbook/Book Chapter

1. A. SILBERSCHATZ, P.B. GALVIN, G. GAGNE (2018), Operating System Concepts, John Wiley & Sons Inc., 10th Edition.
2. Ajay D. Kshemkalyani and Mukesh Singhal, Distributed Computing, Principles, Algorithms and Systems , Cambridge University Press, 2008
3. Das, Sumitabha, Unix Concepts And Applications, 4th Edition, McGraw-Hill Education (India) Pvt Limited, 2017

Online Course Material

1. Foundations of Operating Systems https://nptel.ac.in/courses/106/106/106106144/
2. Distributed Systems https://archive.nptel.ac.in/courses/106/106/106106168/

Course Title	**Computer Organization and Architecture**	Number	CSCxx C-for comprehensive
Department	Computer Science and Engineering		
Offered for	Comprehensive Examination		

Objectives

- Understand the fundamental concepts of computer organization
- Comprehend features of the underlying computer architecture that supports the aforementioned system
- Understand limitations of single core systems, and consequently the need for multi-core Systems

Contents

Processor Design: Layered abstraction of computer systems, Machine instructions and addressing modes. ALU, RISC, CISC, and ASIC/ASIP paradigms, Assembly language programming, Arithmetic of Computers, Hardwired and microprogrammed datapath/control design, Performance Evaluation, Instruction pipelining, Hazards, Multi-core Architecture, Instruction and Data Level Parallelism, CPU design, Hardwired and microprogrammed control **[Book. 1, Chapter 1-6] [Book. 2, Chapter 9-14, 16-17]**

Memory management: Memory hierarchy, Cache, Cache coherence, Cache restriction, Writing strategy, models of consistency, Virtual memory, Performance Evaluation, RAID. **[Book. 1, Chapter 7-8][Book. 2, Chapter 4-6]**

I/O interface: Programmed Driven I/O, DMA, Interrupts **[Book. 2, Chapter 13] [Book. 2, Chapter 7]**

Interfacing: I/O transfer techniques: Program controlled, Interrupt controlled and DMA; Introduction to computer buses, Peripherals and current trends in architectures. **[Book. 1 Chapters 5-7]**

Textbook/Book Chapter

1. John L. Hennessy, David A Patterson (2019), *Computer Organization and Design, The Hardware Software Interface (3rd Edition)* Morgan Kaufmann
2. W. STALLINGS (2015), Computer Organization and Architecture: Designing for Performance, Pearson Education India, 7th Edition.

Online Course Material

1. Foundation of Computer System Design, https://nptel.ac.in/courses/106/106/106106197/
2. Computer Architecture, https://nptel.ac.in/courses/106/106/106106134/

Course Title	**Computer Communication and Networks**	Number	CSCxx C-for comprehensive
Department	Computer Science and Engineering		
Offered for	Comprehensive Examination		

Objectives

- Understand the fundamental working principles of computer network and Internet architecture
- Model data networks and analyze their performance
- Understand the design issues and challenges for the next-generation data networks

Contents

Introduction: Internet architecture and layering, Network edge vs. core, Packet switching **(Book. 1 Chapter 1)**
Application Layer: Application layer protocols: HTTP, DNS, SMTP, FTP, Peer-to-peer applications, End-to-End data, multimedia networking applications (image, audio, video compression) **(Book. 1 Chapter 2,7, Book. 3 Chapter 25-29)**
Transport Layer: TCP error, flow and congestion control, UDP, Algorithms for Congestion Avoidance in Computer Networks, Quality of Service **(Book. 1 Chapter 3, Book.2 Chapter 20, Book.3 Chapter 24)**
Network Layer: Internet Protocol, Routing in data networks: intra- and inter-domain routing Algorithms, e.g., BGP, MPLS, SDN, Internetwork operation**(Book. 1 Chapter 4,5, Book. 2 Chapter 18-19)**
Data Link Layer: Measure of information, entropy, source coding, Error detection and correction, Retransmission strategies- ARQ protocols, framing, Multi-access Communication: Random access techniques, FDMA, TDMA, CDMA, Reservation, polling, token ring and buses, High speed LANs **(Book. 3 Chapter 10-13, Book. 2 Chapter 3-8)**
Physical Layer and Media: Data and Signals, Digital Transmission, Analog Transmission, Bandwidth Utilization: Multiplexing and Spreading, Transmission Media **[Book. 3, Chapter 3- 8]**
Communication theory in Data Networks: Introduction to Queueing theory, Little's theorem, different queueing systems, Priority queueing, Burke's theorem, network of queues **[Book.4, Chapter 3]**
Wireless and mobile networks: WiFi and Cellular Network concepts, Mobility aspects and MobileIP **(Book. 1 Chapter 7, Book. 2 Chapter 14)**

Textbook/Book Chapter

1. K.W. ROSS, J.F. KUROSE (2016), Computer Networks: A Top Down Approach, Pearson, 7th Edition.
2. W. STALLINGS (2013), Data and Computer Communications, Pearson, 10th Edition.
3. Forouzan, B. A., (2007), Data Communication and Networking, 4th Edition, McGraw Hill
4. Bertsekas, D. P. and Gallager, R. G., (1992), Data Networks, 2nd Edition, Prentice Hall

Online Course Material

1. Ghosh, S.K., Chakraborty S., Computer Network and Internet Protocol, NPTEL Course Material, Department of Computer Science and Engineering, IIT Kharagpur, https://archive.nptel.ac.in/courses/106/105/106105183/
2. Modiano, E., Data Communication Networks, MIT OpenCourseWare, Electrical Engineering & Computer Science, Massachusetts Institute of Technology, https://ocw.mit.edu/courses/electrical-engineering-andcomputer-science/6-263j-data-communication-networks-fall-2002/index.htm
3. Pal, A., Data Communication, NPTEL Course Material, Department of Computer Science and Engineering, Indian Institute of Technology Kharagpur,https://nptel.ac.in/courses/106105082/

Course Title:	**Pattern Analysis and Machine Intelligence**	Number	CSEC-xxx
Department	CSE		
Offered for	Comprehensive Examination		

Objective:
Students should be able to demonstrate the fundamental knowledge of machine learning and the capability to learn advanced machine learning concepts.

Contents:

Machine Learning: Linear and Kernel methods, Bayes Classification, Decision Trees, Regression, Bagging and Boosting, Dimensionality reduction, Clustering, Support Vector Machines, Neural Networks [**Book** 2, Chap 9-11,16-18, 20-21]
Deep Learning: Deep Neural Networks, Optimization and Regularization for Deep Learning [**Book** 2, Chap 13-15; **Book** 2, Chap 7-8], Autoencoder, Generative Adversarial Network [**Book** 3, Chap 14, 20; Online Ref 2]

Textbook/Book Chapter
1. Russel S., Norving P., (2010), Artificial Intelligence: A Modern Approach, Pearson.
2. Murphy,K.V., (2022), Probabilistic Machine Learning: An Introduction, MIT Press.
https://github.com/probml/pml-book/releases/latest/download/book1.pdf
3. Richard O. Duda, Peter E. Hart, Peter Elliot Hart, David G. Stork, Pattern Classification, Wiley, 2001

Reference Books:
1. Goodfellow,I., Bengio.,Y., and Courville,A., (2016), Deep Learning, MIT Press.
2. D. KOLLER, N. FRIEDMAN (2009), *Probabilistic Graphical Models: Principles and Techniques,* MIT Press

Online Course Material
1. Video lectures on search algorithms: https://www.youtube.com/@user-lx4cz6mn1i/videos
2. Tutorial on Generative Models: https://www.youtube.com/watch?v=KudkR-fFu_8

Course Title	**Modern Artificial Intelligence**	Number	CSCxx C-for comprehensive
Department	Computer Science and Engineering		
Offered for	Comprehensive Examination		

Objective

1. Students should be able to demonstrate the knowledge of fundamental concepts in artificial intelligence and the capability to learn advanced concepts.

Contents

Reasoning: Probabilistic reasoning, Bayesian networks, Markov Model **[Online Ref 1, Lecture 12-13, 16-19]**
Knowledge Representation: Reasoning patterns in propositional and predicate logic, Ontological engineering [**Book** ref 2]
Decision Making; Planning: Utility theory, MDPs, Game Theory, Planning with state space search, Partial order planning [**Book** ref 2]
Reinforcement Learning: Introduction, Value-based methods, Policy gradient methods, Model-based methods **[Book 1, Chap 3-6; Online Ref 2, Lecture 16]**
Explainability: Explainable and Interpretable AI **[Online Ref 4]**, Causality and Reasoning **[Online Ref 5,6]**

Textbook/Book Chapter

1. D. KOLLER, N. FRIEDMAN (2009), *Probabilistic Graphical Models: Principles and Techniques,* MIT Press
2. Russel, S., and Norvig, P., (2015), Artificial Intelligence: A Modern Approach, 3rd Edition, Prentice Hall
3. Pearl J., The book of why: The new Science of Cause and Effect, Basic Books, 2018
4. Bostrom N., The Ethics of Artificial Intelligence, Cambridge University Press, 2014

Online Course Material

1. Klein, D., and Abbeel, P., UC Berkeley CS188, "Intro to AI". http://ai.berkeley.edu/lecture_videos.html.
2. Ng, A., Stanford University CS229, "Machine Learning". https://see.stanford.edu/Course/CS229
3. Federated Machine Learning: Concept and Applications: https://arxiv.org/pdf/1902.04885.pdf
4. Samek, W., Wiegand, T., and Muller, K.R. (2017), Explainable Artificial Intelligence: Understanding, Visualizing and Interpreting Deep Learning Models, International Telecommunication Union. https://www.itu.int/en/journal/001/Documents/itu2017-5.pdf
5. Guo, R., Cheng, L, Li, J., Hahn, P.R., Liu, H, (2019), A Survey of Learning Causality with Data: Problems and Methods, https://arxiv.org/pdf/1809.09337.pdf.
6. Pearl, J., (2019), The Seven Tools of Causal Inference with Reflections on Machine Learning, Communications of the ACM, vol. 62, No. 3, pp. 54-60. https://ftp.cs.ucla.edu/pub/stat_ser/r481.pdf

Course Title	**Image and Vision Computing (IMAVIS)**	Number	CSCxx C-for comprehensive
Department	Computer Science and Engineering		
Offered for	Comprehensive Examination		

Objectives

Students should have the ability to:

1. Define a problem, specify a system model, formulate constraints and priors on unknown quantities.
2. Identify techniques which can be used to solve the inverse problem; implement, evaluate performance, and assess their merits and limitations under various assumptions and real-data characteristics.
3. Add robustness to estimation procedures and improve methods and systems in terms of algorithmic efficiency.

Contents: Students have to choose any three fractals out of the following four.

Fractal 1:

***Image Processing*:** Image Formation, Color Spaces, Color Correction [**Book** 1, Chapter 2] Dictionary Learning and Sparse Representation for Image Denoising, Inpainting, and Superresolution [**Book** 3, Chapters 14, 15] HDR Images, Exposure Fusion, Tone Mapping. [**Book** 1, Chapter 10], Image Hazing models and Dehazing Algorithms [Online Ref 4], Edge aware abstraction and Bilateral filter and Applications [Online Ref 5]

Fractal 2:

Organizational Primitives: Features and descriptors, Interest points, Edges, Straight lines and patches, Contour extraction, Segmentation, Clustering, Graph-cuts, Energy-based methods **[Book 1, Chap 1-5]**

Fractal 3:

Recovering Scene Attributes from Images: Feature matching and alignment for 2D images and 3D points, Camera pose estimation from a set of 2D point projections, Structure from motion using 2 frames, Dense motion estimation in videos (translation and parametric), Creating photo-mosaics, Stereo correspondence, 3D reconstruction **[Book 1, Chap 6-8; Book 2, Chap 9, 10]**

Fractal 4:

Recognition: Object detection, Face recognition, Instance recognition, Semantic segmentation **[Book 1, Chap 14]**

Deep Representations: Visual CNN architectures (GoogLeNet, ResNet, DenseNet) **[Online Ref 1, 2, 3]**

Textbook/Book Chapter

1. Szeliski, R., (2010)., Computer Vision: Algorithms and Applications, 2nd Edition, Springer International Publishing.
2. Hartley, R., Zisserman, A., (2004), Multiple View Geometry in Computer Vision, 2nd Edition, Cambridge University Press.
3. Elad, M. (2010). Sparse and redundant representations: from theory to applications in signal and image processing. Springer Science & Business Media.

Online Course Material

1. Szegedy et al., (2014), Going Deeper with Convolutions, https://arxiv.org/pdf/1409.4842.pdf.
2. He et al., (2015), Deep Residual Learning for Image Recognition, https://arxiv.org/pdf/1512.03385.pdf.
3. Huang et al., (2016), Densely Connected Convolutional Networks, https://arxiv.org/pdf/1608.06993.pdf.
4. Fattal, Raanan. "Single image dehazing." *ACM transactions on graphics (TOG)* 27.3 (2008): 1-9. https://dl.acm.org/doi/10.1145/1360612.1360671
5. Paris, S., Kornprobst, P., Tumblin, J., & Durand, F. (2009). Bilateral filtering: Theory and applications. Now Publishers Inc. https://people.csail.mit.edu/sparis/publi/2009/fntcgv/Paris_09_Bilateral_filtering.pdf