School of Mathematics and Computer Science

Courses list (Computer Science)

Course Code	Course Title	Credit Structure			
		L	T	P	C
CS 500	Algorithms Lab	0	0	3	2
CS 510	Foundations of Theoretical Computer Science	3	0	0	3
CS 561	Probability & Statistics for Computer Science	3	0	0	3
CS 540	Fundamentals of Computing Systems Design	3	0	3	4
CS 541	System on Chip Design: Hardware-Software Perspectives	3	0	2	4
CS 620	Algebraic Algorithms	3	0	0	3
CS 606	Programming Language Paradigms	3	0	0	3
CS431	Optimization: Theory and Algorithms	3	0	0	3
CS531	High Dimensional Data Science	3	0	0	3
CS442	Geometric Modeling	3	0	0	3

CS606 **Programming Language Paradigm** **(3-0-0-3)**

The purpose of the course is to obtain familiarity with different paradigms of computer programming, chiefly the object-oriented and the functional. The course will look at various aspects of programming languages -- types, memory, binding and scope, blocks, procedural abstraction, data abstraction, encapsulation, polymorphism, control flow, concurrency etc. -- and how they are present in various procedural, object-oriented and functional programming languages. As a case study we will take a closer look at select OOP and functional programming languages.

Textbooks
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1. Findlay, William, Watt, David Anthony - Programming Language Design Concepts
2. Maurizio Gabbrielli, Simone Martini, Programming Languages: Principles and Paradigms

Additional Readings
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1. Bjarne Stroustrup, The C++ Programming Language
2. Robert Harper, Programming in Standard ML
3. Harold Abelson, Gerald Jay Sussman, Julie Sussman, Structure and Interpretation of Computer Programs

CS620 **Algebraic Algorithms** **(3-0-0-3)**

For B.Tech 3rd and 4th year, M.Tech, PhD. Prerequisite: Algorithms course. Syllabus: GCD Algorithm, fast matrix multiplication, Quick introduction to groups: permutation groups, Normal subgroups, relation between group homomorphisms and kernels, rings, ideals, fields, irreducible polynomials, How to construct fields. Fast polynomial multiplication, Polynomial factorization, integer factorization, primality testing.

Textbooks: 1. Joseph Gallian: Contemporary Abstract Algebra

References:

1. Thomas H. Cormen, Charles E. Leiserson, Ronald L. Rivest, and Clifford Stein: Introduction to Algorithms
2. Lecture notes of 'Algebra and Computation' by Ramprasad Saptharishi(TIFR). https://www.tcs.tifr.res.in/~ramprasad/courses/2019algComp/
3. Lecture notes of 'Algebra and Computation' by Madhusudan (then in MIT) http://people.csail.mit.edu/madhu/ST12/
4. Joachim von zur Gathen: Modern Computer Algebra.
5. Rudolf Lidl and Harald Niederreiter: Introduction to Finite Fields and their applications.

CS541 System on Chip Design: Hardware-Software Perspectives (3-0-2-4)

Course Type: Open Elective (PG, UG- sem VII); Ph.D. (EE and CSE)

Description: This course is focused on design and development aspects of system-on-chip design. Students will learn about designing a system that includes both microprocessors and hardware accelerators. Microprocessor programming, design of hardware accelerator, bus architecture, memory communication etc. will be the principal learning outcomes. This course does not cover backend design (fabrication).

Syllabus: This course will take a deep dive in design of system on chip (SoC) involving hardware and software. Design and development of SoC comprising a microprocessor, hardware accelerators, external memory interfaces and the bus/interconnect architecture connecting them together. SoC

FPGAs will be taken as the underlying platform to learn the concepts. Component design for SoC using High Level Synthesis (HLS) and Verilog Hardware Description Language, packaging components as IP cores, bus architectures, interconnect architecture to connect the components to a modern microprocessor like Arm, programming the microprocessor (embedded software development for SoC); Physical design flow (synthesis, placement and routing, timing verification), functional verification transaction level modeling; Architectural exploration of accelerators, C-to-RTL verification; Memory system hierarchy and architecture for SoC; SoC system performance analysis Lab sessions: high level synthesis, using Verilog to design hardware, programming of a modern microprocessor (embedded software development). The course will have a term design project (TDP) to be carried out in groups. TDP needs to be carried out during M.Tech. Lab hours as well as outside of it. TDPs would require teams to build hardware accelerators, program microprocessors and enable communication between various components. TDPs would be based on problems provided by the instructor or suggested by student teams. Real world SoCs are designed in groups and hence TDP is part of this course.

Textbooks

1. Michael Fingeroff. High Level Synthesis Blue BookPrinciples of Computer System Design, 1st Ed. Xlibris. 2010. ISBN: 978-1450097246 2. Michael Keating. The Simple Art of SoC Design - Closing the Gap between RTL and ESL, 1st Ed. Springer-Verlag New York 2011. ISBN: 978-1-4419-8585-9 3. Xilinx user manuals for Vivado HLS, Vivado, Vivado SDK, SDAccel 4. Arm DS-5 user manual References 1. Transaction-Level Modeling with SystemC. F. Ghenassia, 1st Ed. Springer US 2005. ISBN:978-0387-26232-1 2. T. Grotker, S. Liao, G. Martin and S. Swan. System Design with SystemC, 1st Ed. Springer US 2002. ISBN: 978-1-4020-7072-3

CS500 **Algorithms Lab** **(0-0-3-2)**

Course Type: PG including Ph.D.

Description Review of C/C++, Arrays, Pointers, Linkedlist, Tree Data Structure and Traversal, Stack, Queue, Heap, Hash table, Elementary Graph Algorithms

Textbooks The C Programming Language. 2nd Edition. Book by Brian Kernighan and Dennis Ritchie

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CS510 **Foundations of Theoretical Computer Science** **(3-0-0-3)**

Course Type: PG

Description

The objective is to introduce foundations of Theoretical Computer Science.

Syllabus

Propositional logic, First-order logic on words and graphs. Introduction to proofs using Trees and Graphs. Graph algorithms like Maxflow-Mincut. Finite state machines and modelling using FSMs. Introduction to Turing machines, Reductions, Undecidability of Turing machines. Introduction to complexity classes: P, NP. Completeness and Hardness, NP-completeness, NP-complete problems like SAT, Vertex Cover, Hamiltonian paths.

References

1. Nemirovski. Lecture Notes on Modern Convex Optimization. Available online, 2005. 2. Boyd and Vandenberghe: Convex Optimization. Cambridge University Press, 2004. 3. Bertsekas with Nedic and Ozdaglar: Convex Analysis and Optimization. Athena Scientific, 2003.

CS540 Fundamentals of Computing Systems Design Course Code (3-0-3-4)

Course Type: PG including PhD

Description

This course is focused on fundamentals of systems design. Students will learn about different aspects of computing systems design. They will walk through real-world examples and present real-world cases in classroom settings. The aim of this course is to revise most important basic/advanced concepts and turn students into system architects and designers.

Syllabus

This course will present an overview of computing systems design involving software (application and system) and hardware. Students would be expected to gain an understanding of “system level design” involving application development, operating systems, databases, networks, and underlying hardware execution model. The following topics will be covered: introduction to computing systems including mobile computing systems, systems design approach, elements of computer systems organization (application, OS, storage, file systems, computer architecture), enforcing modularity with clients and services, enforcing modularity with virtualization, computing workloads, introduction to performance estimation of systems, network as a system and a system component, fault tolerance in systems, enforcing information security in systems, high availability and redundant system design. Case studies of the design of youtube, twitter, etc. will be discussed.

The course will have a term design project (TDP) to be carried out in groups. TDP needs to be carried out during M.Tech Lab hours as well as outside of it. TDPs would require teams to build small scale systems for specific problems provided by the instructor or suggested by student teams. Real world systems are designed in groups and hence TDP is part of this course.

Textbooks

1. Jerome Saltzer and M. Frans Kaashoek. Principles of Computer System Design, 1st Ed. Elsevier Inc. 2009.Paperback ISBN: 978-0-123-74957-4

2. Raj Jain. The Art of Computer Systems Performance Analysis. John Wiley & Sons. 1991. Indian Edition Available. ISBN: 978-0-471-50336-1

3. Ross Anderson. Security Engineering: A Guide to Building Dependable Distributed Systems. John Wiley & Sons, second edition, 2008. ISBN 9780–470–06852–6

References

1. Radia Perlman. Interconnections, Second Edition: Bridges, Routers, Switches, and Internetworking Protocols. Addison-Wesley, 1999. ISBN: 978–0–201–63448–8.

CS561 Probability and Statistics for Computer Science 3-0-0-3

Objective: The course gives an elementary-level introduction to probability and statistics for engineers and scientists. Along with theory and methods, this course focuses on applications in real-life using statistical computing and graphics tools, e.g., R programming language.

Prerequisite: None

Contents:

- Data visualisation tools and techniques
- Discrete experiments, Probability space, Equally-likely outcomes and combinatorial problems, Non-equally likely outcomes
- Conditional probability, Bayes formula, Independent events
- Random variables, Binomial and Poisson distributions, Expectation, Variance, Linearity of expectation
- Markov and Chebyshev inequalities, simple applications
- Joint distributions, joint densities, correlation
- Statistics, sampling, central limit theorem, hypothesis testing

Suggested Textbooks:

1. Introduction to Probability and Statistics for Engineers and Scientists, S. Ross, 2007

Reference Texts:

1. An Introduction to probability theory and its applications. (Vols. 1, 2), W Feller, 3/e

CS431 **Optimization: Theory and Algorithms** **(3-0-0-3)**

Course Type: Programme Elective
Offered to: UG (3^{rd}, 4^{th}year – CSE& MnC), M.Tech, Ph.D.
Prerequisite: Linear Algebra, Calculus, Programmingexperience (e.g MATLAB, Python)

Course Objective:
The objective is to be able to model problems as optimization problems, identify easy and hard instances of optimization problems, learn theory and techniques for solving linear and nonlinearprogramming problems.

Course Content:
Modelling optimization problems, classes of problems- discrete, continuous, linear, quadratic, unconstrained and constrained
Unconstrained optimization – necessary and sufficient conditions, iterative algorithms: steepest descent, Newton's method, conjugate gradient
Convex Sets, Convex functions, Convex Optimization, Farkas Lemma
Linear Programming- applications in transportation, network flow, Simplex Method, Duality inLPs
Constrained Optimization – KKT conditions, Duality, Conditions for Strong Duality Applications in Machine Learning

Text book(s):

1. David G. Luenberger and Yinyu Ye, Linear and Nonlinear Programming 3rd edition, Springer, ISBN: 978-0387745022

2. Edwin K.P. Chong and Stanislaw H. Zak, An Introduction to Optimization, 2nd edition, Wiley-Interscience Series in Discrete Mathematics and Optimization, ISBN: 0-471-39126-3

3. Stephen Boyd and Lieven Vandenberghe, Convex Optimization, Cambridge University Press, ISBN: 0-521-83378-7

Reference(s):
Jorge Nocedal and Stephen Wright, Numerical Optimization, 2nd edition, Springer, ISBN: 978-0-387-30303-1

R. Fletcher, Practical Methods of Optimization, Wiley, ISBN: 978-0471494638
Bertsimas and Tsitsikilis, Introduction to Linear Optimization, Athena Scientific, ISBN: 978-1886529199

CS531 **High Dimensional Data Science** **(3-0-0-3)**

Course Type: Programme Elective
Offered to: CSE-UG (3rd, 4th year), M.tech, Ph.D.
Prerequisite: Algorithm Design, Probability, Linear algebra,Calculus

Course Objective:
The objective is to understand the theoretical foundations of high dimensional data science.

Course Content:

1. High Dimensional Space - The geometry of high dimension, properties of unit ball, Random projects and Johnson-Lindenstrauss Lemma, Separating gaussians
2. Singular Value Decomposition (SVD) - Introduction to SVD, best k-rank approximations, left singular vectors, power method for SVD, applications of SVD.
3. Compressed sensing

Text book(s): None

Reference(s):

1. Foundations of Data science by Blum, Hopcroft and Kannan
2. Understanding machine learning by Shai Shalev-Shwartz and Shai Ben-David

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CS442 **Geometric Modeling** **(3-0-0-3)**

Course Type: Institute /Programme Elective
Offered to: UG (3rd, 4th year), M.tech, Ph.D.
Prerequisite: Programming, Calculus and Linear Algebra

Course Objective:
This is an introductory course in modelling techniques for 3D objects. It is an institute elective for CS and Non-CS students. It covers a wide range of different ways of representing the geometry of objects. The emphasis in this course will be on the theory and basic principles of constructing models and reasoning about the mathematics of models. Students will be graded based on Quizzes, Mid-Semester exam, Programming Assignments, and an End-semester examination.

Course Content:
1.Coordinate system: Local and global, Point and vectors, Linear maps and affine maps
2. Polygon: Convex and concave; polyhedron; convex hull
3. Parametric equation: Basic differential geometry of curves and surfaces
4. Curves: Explicit/Implicit equations of curves, Hermite curves
5. Bezier Curves: Bezier basis functions, Control points, Continuity, 6. Composite Bezier curves, Rational Bezier curves
6. B-Spline curves: B-Spline basis function, Closed B-Spline curve, NURBS
7. Surfaces: Bezier surfaces, Bicubic Bezier patch, Composite Bezier surfaces, B-Spline Surfaces, Matrix form
8. Solids: Parametric solids, Sweep solids, deformation of solids, Boundary models, Space partitioning models, Boolean models
9. Geometric modelers: Boundary representation modelling, Boundary representation operations
10. Voronoi diagram; Delaunay triangulation

Text book(s):
1. Geometric Modeling by Mortenson, 2nd Edition, Wiley Publishers
2. Curves and Surfaces for Computer Aided Geometric Design by Farin, Academic Press

Reference(s):
1. Applied Geometry for Computer Graphics and CAD, by Marsh 2nd Edition, Springer
2. Computational Geometry in C, by O'Rourke, 2nd Edition, Cambridge University Press

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Courses List

(Mathematics)

Course code	Course Title	Credit Structure			
		L	T	P	C
MTH6011	Graduate Course in Complex Analysis	3	1	0	2
MTH6012	Graduate Course in Functional Analysis	3	1	0	2
MTH6021	Graduate Course in Algebra	3	1	0	2
MTH6022	Graduate Course in Linear Algebra	3	1	0	2
MTH603	Graduate Course in Differential Equations	3	1	0	4
MTH610	Measure Theory and Integration	3	1	0	4

MTH6011 Graduate Course in Complex Analysis 3-1-0-2

Syllabus:

Classification of isolated singularities, Riemann's theorem on removable singularities, Essential Singularities, Casorati-Weierstrass theorem.

Meromorphic functions, Argument principle, winding number, Rouche's theorem and its applications, Open mapping theorem. Maximum Modulus Theorem and its Applications. Schwarz Lemma

Conformal mapping, Mobius transformation,
Weierstrass theorem for infinite products.

Harmonic functions, Poisson integral formula, Mean value Property, Dirichlet problem.

References:

1. Churchill, Brown, Complex variables and Applications. (2009)
2. Stein and Shakarchi, Complex analysis. (2013).
3. Ahlfors, Complex Analysis.
4. Conway, Functions of One Complex Variable.

MTH6012 **Graduate Course in Functional Analysis** **3-1-0-2**

(Review: Hilbert Spaces, Examples, Riesz Representation Theorem. Orthonormal bases.)

Bounded Operators on Hilbert Spaces. Self-adjoint and Normal Operators. Spectral theorem for Compact Normal Operators.

Syllabus:
Orthogonal Projections. Spectral theorem for Normal Operators.

Lp Spaces Holder and Minkowski Inequalities. Completeness of Lp Spaces. Banach Spaces, Examples. Dual of a Banach Space, Hahn Banach Theorem. Weak and weak* topology. Alaoglu's theorem.

Bounded Linear Operators on a Banach Spaces.

Baire Category Theorem. Uniform Boundedness Theorem, Open Mapping Theorem, Closed Graph Theorem.

References:

1. G. Simmons. Introduction to Topology and Modern Analysis.
2. J.B. Conway. A course in Functional Analysis.
3. E. Stein and R. Shakarchi. Real Analysis.
4. E. Stein and R. Shakarchi. Functional Analysis.

MTH6021 **Graduate Course in Algebra** **3-1-0-2**

Syllabus:

Group theory: group action and Sylow's theorem, semidirect product, structure theorem for finitely generated abelian groups.

Rings and modules: UFD, PID, ED, tensor product, noetherian rings, integral extension. Field Theory:

field extensions, Galois theory, finite fields.

Introduction to the representation theory for finite groups.

References:

1. Abstract Algebra, D.S. Dummit and R.M. Foote, Wiley.
2. Algebra, M. Artin, Pearson publication
3. Algebra, S. Lang, Springer GTM

MTH6022 **Graduate Course in Linear Algebra** **3-1-0-2**

Syllabus

Review: Vector spaces, subspaces, bases and dimension, some examples, Linear transformations, rank-nullity theorem.

Syllabus:

Quotient spaces, The algebra of linear transformations and matrices, Determinants, linear functionals, Duality.

Characteristic values, Cayley-Hamilton Theorem, Diagonalizability, Projections, Primary decomposition theorem, Rational and Jordan canonical forms.

Inner product spaces, Spectral Theory, Theory of bilinear and Hermitian forms.

References:

1. C. W. Curtis: Linear Algebra: An Introductory Approach
2. Vikas Bist, Vivek Sahai: Linear Algebra
3. K. Hoffman, R. Kunze: Linear algebra
4. I. Kaplansky: Linear Algebra and Geometry: A second course
5. Nicholas Loehr: Advanced Linear Algebra
6. Steven Roman: Advanced Linear Algebra

MTH603 **Graduate Course in DIfferential Equations** **3-1-0-4**

Syllabus

Ordinary Differential Equations (ODEs): Existence and uniqueness of solutions. Stability analysis. Introduction to optimal control of ODEs.

Syllabus:

Partial Differential Equations (PDEs): First and second-order PDEs. Initial and boundary value problems. Introduction to Hilbert spaces of functions, Sobolev spaces, and the notion of a weak solution.

References:

1. Coddington, E. A., and Levinson, N.: Theory of Ordinary Differential Equations.
2. Clarke, Francis: Functional Analysis, Calculus of Variations and Optimal Control.
3. Evans, L. C.: An Introduction to Mathematical Optimal Control Theory, Version0.2.
4. Evans, L. C.: Partial Differential Equations.
5. Salsa, S.: Partial Differential Equations in Action: From Modelling to Theory.

MTH610 **Measure Theory and Integration** **3-1-0-4**

Syllabus:

The need for Lebesgue integration, Analogy between topological spaces and measurable spaces, Borel sets, Approximating measurable functions by simple functions, Measure spaces, Monotone convergence theorem, Fatou’s lemma, Completion of measure.

Urysohn’s lemma and partition of unity, The Riesz representation theorem for positive linear functionals on $C_c(\mathbb{R}^k)$, Existence of Lebesgue measure, Non-measurable sets, Lusin’s theorem.

Convex functions, Jensen, Hölder and Minkowski inequalities, $(1\leq p<\infty) L^{p}(\mathbb{R}^k)$ as a completion of $C_c(\mathbb{R}^k)$.

Hilbert spaces, Examples, Bessel and Persavel inequalities, Orthonormal basis for $L^2(S^1)$, Hilbert space isomorphism of $L^2(S^1)$ onto ${\ell}^2(\mathbb{Z})$.

Complex measure, Signed measure, Radon-Nikodym theorem, Polar decomposition of a complex measure, Hahn decomposition theorem, Dual spaces of $L^{p}(\mathbb{R}^k)$, Riesz representation theorem revisited for bounded linear functionals on $C_c(\mathbb{R}^k)$, Product measure and Fubini theorem

References:

1. Real and Complex Analysis by Walter Rudin
2. Principles of Real Analysis by Charalambos D. Aliprantis and Owen Burken-shaw
3. Real Analysis by Elias M. Stein and Rami Shakarchi
4. Real Analysis by Halsey L. Royden