SEMESTER S8

COMPUTATIONAL COMPLEXITY

(Common to CS/CM/AD/CB/CN/CU/CR/CI)

Course Code	**PECST864**	**CIE Marks**	40
Teaching Hours/Week (L: T:P: R)	3:0:0:0	**ESE Marks**	60
Credits	3	**Exam Hours**	2 Hrs. 30 Min.
Prerequisites (if any)	PCCST302, PCCST502	**Course Type**	Theory

Course Objectives:

1. To develop an understanding of various computational models, including deterministic and nondeterministic models, Turing machines, and other computational models, and analyze their capabilities and limitations, focusing on how these models influence the classification of problems into complexity classes.
2. To explore key complexity classes such as P, NP, and PSPACE, and apply polynomial-time reductions to prove the NP-completeness of various problems, and also investigate space complexity, polynomial hierarchy, and advanced topics.

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SYLLABUS

Module No.	Syllabus Description	Contact Hours
1	Introduction to Complexity Theory - Basic concepts and motivations, Deterministic and nondeterministic models, Turing machines, and computational models. (Text 2 - Ch 7) Complexity Classes P and NP - Definitions and examples of P and NP, Polynomial-time algorithms, NP-completeness and the Cook-Levin theorem. (Text 2 - Ch 7, 8) Reductions and Completeness - Polynomial-time reductions, NP-complete problems, and their significance, Examples of NP-complete problems (Text 1 - Ch 2)	9
2	Space Complexity - Space complexity classes: L, NL, PSPACE, Savitch's theorem and NL-completeness, PSPACE-completeness. (Text 2 - Ch 8) Polynomial Hierarchy and Alternation - Definition of the polynomial hierarchy (PH), Complete problems for each level of PH, Relationship between PH and other classes. (Text 1 - Ch 5)	9
3	Interactive Proofs - Definition and examples of interactive proofs, IP =	9

	PSPACE theorem, Zero-knowledge proofs. (Text 1 - Ch 8) Probabilistically Checkable Proofs (PCPs) - Introduction to PCPs, PCP theorem and implications, Applications in hardness of approximation. (Text 1 - Ch 9)	
4	Circuit Complexity - Boolean circuits and circuit complexity, Circuit lower bounds, Complexity of specific functions. (Text 2 - Ch 9) Quantum Complexity - Basics of quantum computation, Quantum complexity classes: BQP, QMA, Quantum algorithms and their complexity. (Text 3 - Ch 10, 11)	**9**

Course Assessment Method
(CIE: 40 marks, ESE: 60 marks)

Continuous Internal Evaluation Marks (CIE):

Attendance	Assignment/ Microproject	Internal Examination-1 (Written)	Internal Examination- 2 (Written)	Total
5	**15**	**10**	**10**	**40**

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End Semester Examination Marks (ESE)

In Part A, all questions need to be answered and in Part B, each student can choose any one full question out of two questions

Part A	Part B	Total
• 2 Questions from each module. • Total of 8 Questions, each carrying 3 marks **(8x3 =24 marks)**	• Each question carries 9 marks. • Two questions will be given from each module, out of which 1 question should be answered. • Each question can have a maximum of 3 subdivisions. **(4x9 = 36 marks)**	**60**

Course Outcomes (COs)

At the end of the course students should be able to:

Course Outcome		Bloom's Knowledge Level (KL)
CO1	Describe and interpret different computational models, including deterministic and nondeterministic Turing machines.	**K2**
CO2	Recall and categorize complexity classes such as P, NP, and PSPACE, and explain their fundamental properties.	**K2**
CO3	Use polynomial-time reductions to demonstrate problem completeness and analyze the computational difficulty of problems.	**K3**
CO4	Evaluate problems based on their space complexity and apply theories like Savitch's theorem to assess space-bounded algorithms.	**K4**
CO5	Examine advanced topics in complexity theory, including interactive proofs, PCPs, and quantum complexity, and their implications for computational theory.	**K3**

Note*: K1- Remember, K2- Understand, K3- Apply, K4- Analyse, K5- Evaluate, K6- Create*

CO-PO Mapping Table (Mapping of Course Outcomes to Program Outcomes)

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	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	3	3	3									2
CO2	3	3	3									2
CO3	3	3	3									2
CO4	3	3	3									2
CO5	3	3	3									2

Note: *1: Slight (Low), 2: Moderate (Medium), 3: Substantial (High), -: No Correlation*

Text Books				
Sl. No	**Title of the Book**	**Name of the Author/s**	**Name of the Publisher**	**Edition and Year**
1	Computational Complexity: A Modern Approach	Sanjeev Arora, Boaz Barak	Cambridge University Press	1/e, 2019
2	Introduction to the Theory of Computation	Michael Sipser	Cengage	3/e, 2014
3	Quantum Computing: A Gentle Introduction	Eleanor Rieffel, Wolfgang Polak	MIT Press	1/e, 2014

Reference Books				
Sl. No	**Title of the Book**	**Name of the Author/s**	**Name of the Publisher**	**Edition and Year**
1	Randomized Algorithms	Rajeev Motwani and Prabhakar Raghavan	Cambridge University Press	1/e, 2004
2	Probability and Computing: Randomization and Probabilistic Techniques in Algorithms and Data Analysis	Michael Mitzenmacher and Eli Upfal	Cambridge University Press	3/e, 2017
3	Introduction to Algorithms	Thomas H. Cormen, Charles E. Leiserson, Ronald L. Rivest and Clifford Stein	The MIT Press Cambridge	4/e, 2023
4	The Probabilistic Method	Noga Alon and Joel H. Spencer	Wiley-Blackwell	4/e, 2016
5	Approximation Algorithms	Vijay V. Vazirani	Springer	4/e, 2013
6	Theory of Computation : Classical And Contemporary Approaches	Dexter C Kozen	Springer	6/e, 2006
7	Computational Complexity: A Conceptual Perspective,	Oded Goldreich	Cambridge University Press	1/e, 2008

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Video Links (NPTEL, SWAYAM…)	
Module No.	**Link ID**
1	https://onlinecourses.nptel.ac.in/noc21_cs90/preview https://onlinecourses.nptel.ac.in/noc21_cs49/preview
2	https://onlinecourses.nptel.ac.in/noc21_cs90/preview https://onlinecourses.nptel.ac.in/noc21_cs49/preview
3	https://onlinecourses.nptel.ac.in/noc21_cs90/preview https://onlinecourses.nptel.ac.in/noc21_cs49/preview
4	https://onlinecourses.nptel.ac.in/noc21_cs90/preview https://onlinecourses.nptel.ac.in/noc21_cs49/preview https://archive.nptel.ac.in/courses/106/104/106104241/

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