Lahore University of Management Sciences

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CS 202/EE 202 Data Structures

Spring 2024

Subject to Change

Course Description
Data structures are the key abstractions for storing data in computer systems and thus form an essential building block for efficient algorithms. They are used in the design of a wide variety of applications today including cryptocurrencies (e.g., Bitcoins), search engines (e.g., Bing, Google), social networking (e.g., Twitter, Facebook), and data processing frameworks for machine learning and data science (e.g., Spark and Tensorflow). Thus, a sound conceptual understanding of data structures and experience with implementing them is a highly sought-after skill in the technology industry and beyond. This course introduces the fundamentals of data structures and aims to provide a deep understanding of how different ways of structuring information in computer systems leads to different design tradeoffs. Students will be introduced to analytical tools for comparing different data structures in terms of their time and space complexities. The course will augment student's theoretical understanding with rigorous programming assignments, which form an essential component of the course.

COURSE DISTRIBUTION	
Core	Yes
Elective	No
Open for Student Category	All (whoever satisfies the course prerequisite)
Close for Student Category	None

COURSE PREREQUISITE(S)	
CS 200	Introduction to Programming

Course Teaching Methodology
• **Teaching Methodology**:Synchronous (Live Lectures)• **Lecture details**: Lectures will be conducted live over Zoom. The lecture recordings will be made available to students for later viewing. Moreover, links to related reference material or resources may be provided from time to time.

COURSE OFFERING DETAILS				
Credit Hours	3			
Lectures	Nbr of Lec(s) Per Week	2	Duration	75 mins
Labs	Nbr of Lec(s) Per Week	None	Duration	
Tutorials	Nbr of Lec(s) Per Week	TBA	Duration	

Instructor	Dr. Ihsan Ayyub Qazi
Room No.	SBASSE 9-G14A
Class Timings	2pm-3:15pm Wed/Fri
Office Hours	TBA
Email	ihsan.qazi@lums.edu.pk
Telephone	8368
TA	TBD
TA Office Hours	TBA
Course URL (if any)	lms.lums.edu.pk

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Course Basics				
Credit Hours	3			
Lectures	Nbr of Lec(s) Per Week	2	Duration	75 mins
Labs	Nbr of Lec(s) Per Week	None	Duration	
Tutorials	Nbr of Lec(s) Per Week	TBA	Duration	

PROGRAM EDUCATIONAL OBJECTIVES (PEOs)	
PEO-01	Demonstrate excellence in profession through in-depth knowledge and skills in the field of Computing.
PEO-02	Engage in continuous professional development and exhibit quest for learning.
PEO-03	Show professional integrity and commitment to societal responsibilities.

Course Objectives	
CO-1	To understand the fundamental tradeoffs in the design of common data structures
CO-2	To introduce tools for analyzing the time and space complexity of data structures and algorithms
CO-3	To provide rigorous 'hands-on' experience with implementing different data structures in a programming language

Course Learning Outcomes (CLOs)	
CLO1	Students will be able to understand the working of basic data structures
CLO2	Students will be able to understand the fundamental tradeoffs in the design of data structures
CLO3	Students will be able to compare the time and space efficiency of different data structures
CLO4	Students will be able to appreciate how changing application requirements can lead to new data structures
CLO5	Students will be able to write programs to efficiently store, retrieve, and manipulate data.

CLO	**CLO Statement**	**Bloom's Cognitive Level**	**PLOs/Graduate Attributes (Seoul Accord)**
CLO1	Students will be able to understand the working of basic data structures	C1	PLO2
CLO2	Students will be able to understand the fundamental tradeoffs in the design of data structures	C1, C2	PLO2
CLO3	Students will be able to compare the time and space efficiency of different data structures	C3, C4	PLO3
CLO4	Students will be able to appreciate how changing application requirements can lead to new data structures	C4	PLO3, PLO4
CLO5	Students will be able to write programs to efficiently store, retrieve, and manipulate data	C5, C6	PLO4, PLO5

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Grading Breakup and Policy:

Assessment	Weight (%)	Related CLOs	ACM Recommended Disposition
Assignment	30%	CLO1, CLO3, CLO5	D3, D4, D7, D9
Quizzes	25%	CLO1, CLO2, CLO3, CLO4 CLO5	D4, D7, D9
Mid Term Exam	30%	CLO1, CLO2, CLO3, CLO4, CLO5	D4, D7, D9
Final Exam	15%	CLO1, CLO2, CLO3, CLO4, CLO5	D4, D7, D9

Lectures

- There will be 2 lectures per week over the course of the semester.
- Lectures will be conducted live over Zoom. We will also be recording the lectures, which will be made available to students for later viewing
  - The recordings of the lectures will be posted on YouTube.
  - Each lecture will also have a Piazza thread for students to ask questions. Live questions will be taken over Zoom during the lectures
- The instructor and the TAs will also be hosting office hours per week.

Assignments

Assignments are designed to help students develop an in-depth understanding of the practical aspects of ideas and concepts presented in the lectures. Their aim is to integrate these ideas with real-world implementations.

- In total, there will be 5 assignments.
- The primary form of support students will have for assignments are the office hours we'll host, and Piazza.

Quizzes

- We will have 8 quizzes in the course but only the best 6 quizzes will be counted towards your grade. An important purpose of having N-2 quizzes is to account for all issues (e.g., Internet connectivity, electricity outage, sickness, etc) that may prevent you from taking the quiz. No request for a makeup quiz will be entertained if you miss up to 3 quizzes irrespective of the reason. In the exceptional situation in which you end up missing more than 3 quizzes, we will consider a makeup quiz only if there is a valid justification. In that case, we reserve the right to determine the mode of the quiz, which may be oral or textual.
- All quizzes will take place during class timings and will be 10-15mins in duration
- All quizzes will be announced (see schedule below for the quiz dates)
- The syllabus for every quiz will include everything covered before the lecture in which the quiz will be taken

Please refer to Student Handbook 2019-20, page 37, article 25, titled "Makeup Policy for Graded Instruments".
"In case N-X policy is implemented for an instrument having multiple sub instruments then petitions will not be accepted for that instrument".

Office Hours

- We'll be dividing the class into groups of roughly equal sizes. Each group will be assigned one primary TA, who will be responsible for guiding and helping students especially during office hours.
- We plan on hosting roughly ~15 hours of staff office hours every week.

Exam

We will have one midterm exam and one final exam, both of which will be conducted synchronously.

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Academic Honesty

The principles of truth and honesty are recognized as fundamental to the community of learners. This means that all academic work shall be done by the student to whom it is assigned without unauthorized aid of any kind. All forms of academic dishonesty (e.g., plagiarism, cheating) are prohibited. Any instance of academic dishonesty in this course (intentional or unintentional) will be dealt with swiftly and severely. Potential penalties include receiving a failing grade on the assignment in question or in the course overall and forwarding of the case to the disciplinary committee. For further information about this, please make yourself familiar with the relevant sections of the LUMS student handbook.

We believe that most students can distinguish between helping other students understand course material and cheating. Explaining a subtle point from lecture or discussing course topics is an interaction that we encourage. However, all coursework must be completed individually and independently unless explicitly stated otherwise (e.g., in case of projects). We have various methods of detecting cheating – so please don't do it! We also ask that you do not post your assignment solutions publicly.

Some general points

- You are encouraged to discuss problems and ideas but the final solution (in programming assignments) must be yours
    - Never have someone else's code in your possession at any time
    - Never give anyone your code
    - Do not copy code from the Internet
    - If in doubt, talk to the course staff
- All programming assignments must be completed individually
    - May discuss understanding of problem statement and a general sketch of approach
    - May not discuss details of solution
    - May not show your solution to others (this year or in future years)
    - May not look at others' solutions (this year or from past years)
- We use code comparison software
    - Immune to obfuscation
    - Produces color-coded all-student-pairs code comparisons

Cheating besides being unethical also has many profound negative consequences:

- It takes away your opportunity for learning and lowers your confidence
- You'd never get this time back!
- Negatively impacts your colleagues

Rather than copying someone else's work, ask for help. The entire course staff is here to help you succeed. If you invest the time to learn the material and complete the assignments, you won't need to copy any answers.

We want you to succeed!

If you are feeling overwhelmed, come to our office hours and talk with us. We know university life can be stressful – and especially so during the COVID-19 pandemic – and we want to help you succeed.

Harassment Policy

SBASSE, LUMS and particularly this class, is a harassment free zone. There is absolutely zero tolerance for any behaviour that is intended or has the expected result of making anyone uncomfortable and negatively impacts the class environment, or any individual's ability to work to the best of their potential. In case a differently-abled student requires accommodations for fully participating in the course, students are advised to contact the instructor so that they can be facilitated accordingly.

If you think that you may be a victim of harassment, or if you have observed any harassment occurring in the purview of this class, please reach out and speak to me. If you are a victim, I strongly encourage you to reach out to the Office of Accessibility and Inclusion at oai@lums.edu.pk or the sexual harassment inquiry committee at harassment@lums.edu.pk for any queries, clarifications, or advice. You may choose to file an informal or a formal complaint to put an end of offending behavior. You can find more details regarding the LUMS sexual harassment policy here. To file a complaint, please write to harassment@lums.edu.pk.

SSE Council on Equity and Belonging

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In addition to LUMS resources, SBASSE's Council on Belonging and Equity is committed to devising ways to provide a safe, inclusive and respectful learning environment for students, faculty and staff. To seek counsel related to any issues, please feel free to approach either a member of the council or email at cbe.sse@lums.edu.pk

Rights and Code of Conduct for Online Teaching

A misuse of online modes of communication is unacceptable. TAs and Faculty will seek consent before the recording of live online lectures or tutorials. Please ensure if you do not wish to be recorded during a session to inform the faculty member. Please also ensure that you prioritize formal means of communication (email, LMS) over informal means to communicate with course staff.

Makeup Policy

- Please refer to Student Handbook 2019-20, page 37, article 25, titled "Makeup Policy for Graded Instruments".
- *"In case N-X policy is implemented for an instrument having multiple sub instruments then petitions will not be accepted for that instrument".*

Examination Detail

Midterm Exam	Yes/No: Yes
Final Exam	Yes/No: Yes Combine Separate: Duration: Exam Specifications:

Code of Conduct

1. When attending classes, please ensure that your video is off, and your mic is muted unless you are asked to do so.
2. All quizzes will be announced (in fact, they have already been specified in the schedule below) and students must ensure that their devices are charged and they have a stable internet connection (including smartphones).
3. All assessments including quizzes and the final exam will be timed. Make sure you are able to start them on time.

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Lec.	Topics	Assessments	Related CLOs	ACM Computing Knowledge Landscape
1	Overview: Data Structures, Abstract Data Types, and Applications • What are data structures? Why do they matter? • What are abstract data types? How do they relate with data structures? • Applications of data structures		CLO1	
Module-1: Analysis Tools and Linear Data Structures				
2	Analysis Tools: Experimental Analysis, Asymptotic Notation • How can we analyze the efficiency of algorithms and data structures they use? • What is experimental analysis? What is asymptotic analysis? How do they compare?		CLO1, CLO2, CLO3	
3	Asymptotic Analysis and Arrays • Big-O analysis • How can we realize the List abstract data type?		CLO1, CLO2, CLO3	
4	Lists and Stacks • Singly and doubly linked lists • Implementing a Stack ADT (Last-In First-Out ordering) • Analysis and practice	QUIZ-1	CLO1, CLO2, CLO3, CLO5	
5	Queues, Practice • Implementing a Queue ADT (First-In First-Out ordering) • Analysis and practice		CLO1, CLO2, CLO3, CLO5	
Module-2: Trees, Binary Search Trees, and M-ary Trees				
6	Trees and Tree Traversals • What is a tree? What are rooted trees? • How can we systematically traverse a tree? Inorder, preorder, postorder traversals		CLO1, CLO2, CLO3, CLO4, CLO5	
7	Tree Traversals and Binary Trees • Level-order traversal • Representing binary trees • Analysis of binary trees (e.g., relationship between number of nodes and height of a tree)	QUIZ-2	CLO1, CLO2, CLO3, CLO4, CLO5	
8	Binary Search Trees (BST): Basics, BST Analysis • What are BSTs? • BST operations: search and insertion • How can we implement a BST?		CLO1, CLO2, CLO3, CLO4, CLO5	
9	BSTs and Balanced BSTs Trees • Deletions in BSTs • What are AVL trees? Height-balance property and analysis of AVL trees		CLO1, CLO2, CLO3, CLO4, CLO5	

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10	Balanced Binary Trees: AVL Trees • Single and double rotations • AVL search, insertion and deletion	QUIZ-3	CLO1, CLO2, CLO3, CLO4, CLO5	
11	B+ Trees • Towards m-ary trees • What are B+ trees? Why do we need them? • B+ tree operations		CLO1, CLO2, CLO3,	
Module-3: Hash Tables, Priority Queues, and Heaps				
12	Hash Tables: Hash Functions, Chaining • What are hash tables? What are hash functions? • Hash tables with chaining • Analysis of hash tables		CLO1, CLO2, CLO3, CLO4, CLO5	
13	Hash Tables: Open Addressing • Hash tables with open addressing • Linear probing and double hashing	QUIZ-4	CLO1, CLO2, CLO3, CLO4, CLO5	
14	**Mid-term Exam**			
15	Priority Queues and Heaps • How can we implement a priority queue? • What are heaps? • Heap operations		CLO1, CLO2, CLO3, CLO4, CLO5	
Module-4: Sorting and Data Compression				
16	Sorting: Insertion Sort, Selection Sort, and Mergesort • How can we implement basic sorting algorithms? • What is the impact of data structures on the efficiency of sorting algorithms?		CLO1, CLO2, CLO3, CLO4, CLO5	
17	Sorting: Quicksort, External Sort • Quicksort and pivot selection • Sorting big data	QUIZ-5	CLO1, CLO2, CLO3, CLO4, CLO5	
18	Sorting: Lower Bound on Sorting, Bucket-Sort, Radix-Sort (optional) • Bounds on comparison-based sorting • Linear-time sorting		CLO1, CLO2, CLO3, CLO4, CLO5	
19	Data Compression: Applications, Huffman Coding • Applications of data compression • Huffman coding		CLO1, CLO2, CLO3, CLO4, CLO5	
20	Tries: Standard, Compressed, Suffix Tries • Efficient prefix search • Understanding tries • Types of tries	QUIZ-6	CLO1, CLO2, CLO3, CLO4, CLO5	

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Module-5: Graphs and Graph Applications				
21	Graphs: Basics, Data Structures for Graphs • What are graphs? What is the difference between directed and undirected graphs? • What are some basic graph data structures?		CLO1, CLO2, CLO3, CLO4, CLO5	
22	Graph Traversals: Depth First Search, Breadth First Search • How can we systematically traverse a graph? • How can we solve different problems on graphs		CLO1, CLO2, CLO3, CLO4, CLO5	
23	Weighted Graphs: Directed Graphs, Minimum Spanning Trees • How do we represent weighted graphs? • What are spanning trees? • How can find the minimum spanning tree in a graph?	QUIZ-7	CLO1, CLO2, CLO3, CLO4, CLO5	
24	Weighted Graphs: Topological Sort • What is topological sort? • What are some ways to determine the topological sort of vertices in a graph?		CLO1, CLO2, CLO3, CLO4, CLO5	
25	Shortest-Path Algorithms • When is the shortest-path well-defined? • How can we find shortest paths in a graph? What is the impact of the choice of data structures on the complexity of shortest-path algorithms	QUIZ-8	CLO1, CLO2, CLO3, CLO4, CLO5	
26	Shortest-Path Algorithms: Dijkstra's Algorithm • Understanding Dijkstra's algorithm • Time Complexity of Dijkstra's algorithm		CLO1, CLO2, CLO3, CLO4, CLO5	
Module-6: Advanced Topics and Review				
27	Advanced DS Problems • Distributed Hash Tables • Bloom Filters		CLO2, CLO3, CLO4, CLO5	
28	Advanced Topics & Final Review		CLO2, CLO3, CLO4, CLO5	

Textbook(s)/Supplementary Readings

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Appendix A
Bloom's Taxonomy

BLOOM's TAXONOMY*	
1 - Remember 2 - Understand 3 - Apply 4 - Analyze 5 - Evaluate 6 - Create	• Recall facts and basic concepts • Explain ideas or concepts • Use information in new situations • Draw connection among ideas • Justify a stand or decision • Produce new or original work

https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/

Appendix B
ACM Dispositions Table - I

ACM Dispositions			
Element	**Elaboration**	**Element**	**Elaboration**
D1 Adaptable:	Flexible; agile, adjust in response to change	D7 Professional:	Professionalism, discretion, ethical, astute
D2 Collaborative:	Team player; willing to work with others	D8 Purpose-driven:	Goal driven, achieve goals, business acumen
D3 Inventive:	Exploratory; Look beyond simple solutions	D9 Responsible:	Use judgment, discretion, act appropriately
D4 Meticulous:	Attentive to detail; thoroughness, accurate	D10 Responsive:	Respectful; react quickly and positively
D5 Passionate:	Conviction, strong commitment, compelling	D11 Self-directed:	Self-motivated, determination, independent
D6 Proactive:	With initiative, self-starter, independent		

ACM Dispositions Table - II

Class Assessments and Proposed Dispositions												
Assessment Type	**D1 Adaptable**	**D2 Collaborative**	**D3 Inventive**	**D4 Meticulous**	**D5 Passionate**	**D6 Proactive**	**D7 Professional**	**D8 Purpose-driven**	**D9 Responsible**	**D10 Responsive**	**D11 Self-directed**	**Included**
Quiz				✓			✓		✓			Yes
Assignment-Individual			✓	✓			✓		✓			Yes
Assignment-Group		✓	✓	✓			✓		✓	✓		Yes
Project-Individual	✓		✓	✓	✓	✓	✓	✓	✓		✓	Yes
Project- Group	✓	✓	✓	✓	✓	✓	✓	✓	✓			Yes
Presentation-Individual				✓			✓		✓	✓	✓	Yes
Presentation-Group		✓		✓			✓		✓	✓		Yes
Labs-Individual			✓	✓			✓		✓			Yes
Labs- Group		✓	✓	✓			✓		✓	✓		Yes
Exams				✓			✓		✓			Yes
Included	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	

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Appendix C
ACM Computing Knowledge Landscape Table

ACM Computing Knowledge Landscape (CK)			
1. Users and Organizations	CK1.1: Social Issues and Professional Practice CK1.2: Security Policy and Management CK1.3: IS Management and Leadership CK1.4: Enterprise Architecture CK1.5: Project Management CK1.6: User Experience Design	**4. Software Development**	CK4.1: Software Quality, Verification and Validation CK4.2: Software Process CK4.3: Software Modeling and Analysis CK4.4: Software Design CK4.5: Platform-Based Development
2. Systems Modeling	CK2.1: Security Issues and Principles CK2.2: Systems Analysis & Design CK2.3: Requirements Analysis and Specification CK2.4: Data and Information Management	**5. Software Fundamentals**	CK5.1: Graphics and Visualization CK5.2: Operating Systems CK5.3: Data Structures, Algorithms and Complexity CK5.4: Programming Languages CK5.5: Programming Fundamentals CK5.6: Computing Systems Fundamentals
3. Systems Architecture and Infrastructure	CK3.1: Virtual Systems and Services CK3.2: Intelligent Systems (AI) CK3.3: Internet of Things CK3.4: Parallel and Distributed Computing CK3.5: Computer Networks	**6. Hardware**	CK6.1: Architecture and Organization CK6.2: Digital Design CK6.3: Circuits and Electronics CK6.4: Signal Processing