



**National University of Engineering (UNI)**  
School of Computer Science  
Syllabus 2026-I

## 1. COURSE

CS210. Algorithms and Data Structures (Mandatory)

## 2. GENERAL INFORMATION

|                                   |                                                                 |
|-----------------------------------|-----------------------------------------------------------------|
| <b>2.1 Course</b>                 | : CS210. Algorithms and Data Structures                         |
| <b>2.2 Semester</b>               | : 4 <sup>th</sup> Semester.                                     |
| <b>2.3 Credits</b>                | : 4                                                             |
| <b>2.4 Hours</b>                  | : 2 HT; 4 HP;                                                   |
| <b>2.5 Duration of the period</b> | : 16 weeks                                                      |
| <b>2.6 Type of course</b>         | : Mandatory                                                     |
| <b>2.7 Learning modality</b>      | : Face to face                                                  |
| <b>2.8 Prerequisites</b>          | : CS113. Objects-oriented programming II. (3 <sup>rd</sup> Sem) |

## 3. PROFESSORS

Meetings after coordination with the professor

## 4. INTRODUCTION TO THE COURSE

This course provides a comprehensive study of fundamental data structures and algorithms with emphasis on implementation using advanced C++ features. Building on prior C++ knowledge, students will implement generic data structures using templates and traits, ensuring type flexibility and performance. The course covers linear structures (vectors, various linked lists), tree structures (binary, AVL, B-trees), heaps, hash tables, tries, and concurrent data structures. Special focus is placed on modern C++ techniques including variadic templates for generic operations and concurrent programming for thread-safe data structures.

## 5. GOALS

- Implement generic data structures using templates and traits.
- Master advanced tree structures and balanced trees.
- Understand and implement concurrent data structures.
- Apply variadic templates for generic operations on containers.
- Analyze algorithmic complexity of all implemented structures.
- Design efficient data structures for specific problem constraints.

## 6. COMPETENCES

**AG-C08)** Problem Analysis: Identifies, formulates, and analyzes complex computing problems. (Usage)

**AG-C09)** Design and Development of Solutions: Designs, implements, and evaluates solutions for complex computing problems. (Usage)

## 7. TOPICS

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| <b>Unit 1: Advanced Foundation for Data Structures (8 hours)</b>                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Competences Expected: AG-C08,AG-C09</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Topics</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | <b>Learning Outcomes</b>                                                                                                                                                                                                                                                                                                                                                     |
| <ul style="list-style-type: none"> <li>• Template metaprogramming review and advanced traits.</li> <li>• Type traits and SFINAE for conditional compilation.</li> <li>• Variadic templates and parameter packs.</li> <li>• Perfect forwarding and universal references.</li> <li>• Lambda expressions with generic captures.</li> <li>• Policy-based design and CRTP (Curiously Recurring Template Pattern).</li> <li>• Concept-based constraints (C++20 concepts if applicable).</li> </ul> | <ul style="list-style-type: none"> <li>• Design type traits for customizing data structure behavior [Usar].</li> <li>• Implement variadic templates for generic container operations [Usar].</li> <li>• Apply policy-based design to create configurable data structures [Evaluar].</li> <li>• Use perfect forwarding to implement efficient constructors [Usar].</li> </ul> |
| <b>Readings :</b> [Str13], [VJG17]                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                              |

| Unit 2: Estructuras de Datos Fundamentales (8 hours)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
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| Competences Expected: AG-C08,AG-C09                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Topics                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Learning Outcomes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <ul style="list-style-type: none"> <li>• Tipo de Dato Abstracto (ADT) y operaciones sobre un ADT: <ul style="list-style-type: none"> <li>– Operaciones de diccionario (insertar, eliminar, encontrar)</li> </ul> </li> <li>• Arreglos: <ul style="list-style-type: none"> <li>– Numéricos vs no numéricos, cadenas de caracteres</li> <li>– Unidimensionales (vector) vs multidimensionales (matriz)</li> </ul> </li> <li>• Registros/Estructuras/Tuplas y Objetos</li> <li>• Listas enlazadas (por razones históricas): <ul style="list-style-type: none"> <li>– Simples vs Dobles y Lineales vs Circulares</li> </ul> </li> <li>• Pilas</li> <li>• Colas y deque: <ul style="list-style-type: none"> <li>– Cola de prioridad basada en montículo</li> </ul> </li> <li>• Tablas/mapas hash: <ul style="list-style-type: none"> <li>– Resolución de colisiones y complejidad (por ejemplo, sondeo, encadenamiento, rehash)</li> </ul> </li> <li>• árboles: <ul style="list-style-type: none"> <li>– Binarios, n-arios y árboles de búsqueda</li> <li>– Balanceados (por ejemplo, AVL, Rojo-Negro, Montículo)</li> </ul> </li> <li>• Conjuntos</li> </ul> | <ul style="list-style-type: none"> <li>• Para cada ADT/Estructura de Datos en esta unidad: <ul style="list-style-type: none"> <li>– Explicar su definición, propiedades, representación(es) y operaciones de ADT asociadas.</li> <li>– Explicar paso a paso cómo las operaciones de ADT asociadas con la estructura de datos la transforman.</li> </ul> </li> </ul> <p>[Usar]</p> <ul style="list-style-type: none"> <li>• Para cada algoritmo en esta unidad explicar paso a paso cómo opera el algoritmo [Usar]</li> <li>• Implement vector with customizable allocation policy using templates [Usar].</li> <li>• Design generic linked list nodes with trait-based memory management [Usar].</li> <li>• Compare time/space complexity of different linear structures [Evaluar].</li> <li>• Apply variadic templates to initialize containers with multiple elements [Usar].</li> </ul> |
| <b>Readings :</b> [Cor+09], [Str13]                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |

| Unit 3: Estructuras de Datos Fundamentales (8 hours)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
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| Competences Expected: AG-C08,AG-C09                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Topics                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Learning Outcomes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <ul style="list-style-type: none"> <li>• árboles: <ul style="list-style-type: none"> <li>– Binarios, n-arios y árboles de búsqueda</li> <li>– Balanceados (por ejemplo, AVL, Rojo-Negro, Montículo)</li> </ul> </li> <li>• Binary tree template implementation with iterator support.</li> <li>• Binary search tree with trait-based comparison operators.</li> <li>• Tree traversal algorithms (iterative and recursive).</li> <li>• Expression trees and their applications.</li> <li>• Template-based node structures with configurable payload.</li> </ul> | <ul style="list-style-type: none"> <li>• Dados los requisitos para un problema, desarrollar múltiples soluciones usando varias estructuras de datos y algoritmos. Posteriormente, evaluar la idoneidad, fortalezas y debilidades seleccionando un enfoque que satisfaga mejor los requisitos [Evaluar]</li> <li>• Explicar factores más allá de la eficiencia computacional que influyen en la elección de algoritmos, como el tiempo de programación, la mantenibilidad y el uso de patrones específicos de la aplicación en los datos de entrada [Familiarizarse]</li> <li>• Implement generic binary tree with configurable traversal order [Usar].</li> <li>• Design expression tree evaluator using visitor pattern [Usar].</li> <li>• Analyze tree operation complexities for different balancing strategies [Evaluar].</li> </ul> |
| Readings : [Cor+09], [Knu97]                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |

| Unit 4: Balanced and Multi-way Trees (8 hours)                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                   |
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| Competences Expected: AG-C08,AG-C09                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                   |
| Topics                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Learning Outcomes                                                                                                                                                                                                                                                                                                                                 |
| <ul style="list-style-type: none"> <li>• AVL tree implementation with template-based balancing trait.</li> <li>• Red-black tree properties and operations.</li> <li>• B-Tree template implementation for disk-based storage.</li> <li>• 2-3 Tree and 2-3-4 Tree structures.</li> <li>• Digital trie (prefix tree) implementation.</li> <li>• Suffix trees and their applications in string processing.</li> <li>• Node splitting/merging strategies for B-trees.</li> </ul> | <ul style="list-style-type: none"> <li>• Implement self-balancing trees using policy-based design [Usar].</li> <li>• Design B-tree for database index applications [Usar].</li> <li>• Evaluate trade-offs between different balanced tree structures [Evaluar].</li> <li>• Implement trie for efficient string prefix matching [Usar].</li> </ul> |
| Readings : [Cor+09], [Knu97], [SW11]                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                   |

| Unit 5: Estructuras de Datos Fundamentales (8 hours)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
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| Competences Expected: AG-C08,AG-C09                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Topics                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Learning Outcomes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <ul style="list-style-type: none"> <li>• árboles: <ul style="list-style-type: none"> <li>– Binarios, n-arios y árboles de búsqueda</li> <li>– Balanceados (por ejemplo, AVL, Rojo-Negro, Montículo)</li> </ul> </li> <li>• Binary heap implementation using array representation.</li> <li>• Min-heap and max-heap variants.</li> <li>• Heapify algorithms and complexity analysis.</li> <li>• Priority queue ADT implementation.</li> <li>• Binomial heap and Fibonacci heap overview.</li> <li>• Heap applications: Dijkstra's algorithm, heap sort.</li> </ul> | <ul style="list-style-type: none"> <li>• Explicar la propiedad de montículo y el uso de montículos como una implementación de una cola de prioridad [Familiarizarse]</li> <li>• Implement generic heap with configurable comparison trait [Usar].</li> <li>• Design priority queue supporting multiple priority update strategies [Usar].</li> <li>• Analyze heap operations complexity for different heap types [Evaluar].</li> <li>• Apply heap in graph algorithm implementations [Usar].</li> </ul> |
| Readings : [Cor+09], [SW11]                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

| Unit 6: Estructuras de Datos Fundamentales (8 hours)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
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| Competences Expected: AG-C08,AG-C09                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Topics                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Learning Outcomes                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <ul style="list-style-type: none"> <li>• Tablas/mapas hash: <ul style="list-style-type: none"> <li>– Resolución de colisiones y complejidad (por ejemplo, sondeo, encadenamiento, rehash)</li> </ul> </li> <li>• Hash function design and properties.</li> <li>• Separate chaining implementation with linked lists.</li> <li>• Open addressing: linear probing, quadratic probing, double hashing.</li> <li>• Perfect hashing and minimal perfect hashing.</li> <li>• Cuckoo hashing and hopscotch hashing.</li> <li>• Hash table resizing strategies and load factor management.</li> </ul> | <ul style="list-style-type: none"> <li>• Explicar cómo se maneja la evitación de colisiones y la resolución de colisiones en tablas hash [Familiarizarse]</li> <li>• Design generic hash table with configurable collision resolution [Usar].</li> <li>• Implement custom hash functions for user-defined types [Usar].</li> <li>• Evaluate performance of different hashing schemes [Evaluar].</li> <li>• Apply hash tables in compiler symbol table implementation [Usar].</li> </ul> |
| Readings : [Cor+09], [Knu97]                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

| Unit 7: Concurrent Data Structures (8 hours)                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                      |
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| Competences Expected: AG-C08,AG-C09                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                      |
| Topics                                                                                                                                                                                                                                                                                                                                                                                                                        | Learning Outcomes                                                                                                                                                                                                                                                                                                                                                    |
| <ul style="list-style-type: none"> <li>• Thread-safe data structure design principles.</li> <li>• Lock-based concurrent linked lists.</li> <li>• Lock-free and wait-free algorithms.</li> <li>• Concurrent hash tables with fine-grained locking.</li> <li>• Atomic operations and memory ordering.</li> <li>• Concurrent queues (bounded and unbounded).</li> <li>• Concurrent stacks and elimination techniques.</li> </ul> | <ul style="list-style-type: none"> <li>• Design thread-safe data structures using mutex and lock guards [Usar].</li> <li>• Implement lock-free linked list using atomic operations [Usar].</li> <li>• Analyze performance of concurrent vs sequential data structures [Evaluar].</li> <li>• Apply concurrent queues in producer-consumer patterns [Usar].</li> </ul> |
| Readings : [HS12], [Wil19]                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                      |

| Unit 8: Specialized Structures and Applications (8 hours)                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                      |
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| Competences Expected: AG-C08,AG-C09                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                      |
| Topics                                                                                                                                                                                                                                                                                                                                                                                                                                      | Learning Outcomes                                                                                                                                                                                                                                                                                                                                                                    |
| <ul style="list-style-type: none"> <li>• Persistent data structures.</li> <li>• Disjoint-set union (union-find) with path compression.</li> <li>• Bloom filters and their probabilistic properties.</li> <li>• Skip lists for probabilistic balanced search.</li> <li>• Segment trees and Fenwick trees for range queries.</li> <li>• Spatial data structures: k-d trees, quadtrees.</li> <li>• Cache-oblivious data structures.</li> </ul> | <ul style="list-style-type: none"> <li>• Implement persistent data structures with structural sharing [Usar].</li> <li>• Design union-find with both union by rank and path compression [Usar].</li> <li>• Apply specialized structures to solve domain-specific problems [Evaluar].</li> <li>• Evaluate space-time tradeoffs in probabilistic data structures [Evaluar].</li> </ul> |
| Readings : [Oka99], [SW11]                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                      |

## 8. WORKPLAN

### 8.1 Methodology

Individual and team participation is encouraged to present their ideas, motivating them with additional points in the different stages of the course evaluation.

### 8.2 Theory Sessions

The theory sessions are held in master classes with activities including active learning and roleplay to allow students to internalize the concepts.

### 8.3 Practical Sessions

The practical sessions are held in class where a series of exercises and/or practical concepts are developed through problem solving, problem solving, specific exercises and/or in application contexts.

## 9. EVALUATION SYSTEM

\*\*\*\*\* EVALUATION MISSING \*\*\*\*\*

## 10. BASIC BIBLIOGRAPHY

- [Knu97] Donald E. Knuth. *The Art of Computer Programming, Volume 1: Fundamental Algorithms*. 3rd. Addison-Wesley, 1997.
- [Oka99] Chris Okasaki. *Purely Functional Data Structures*. Cambridge University Press, 1999.
- [Cor+09] Thomas H. Cormen et al. *Introduction to Algorithms*. 3rd. MIT Press, 2009.
- [SW11] Robert Sedgewick and Kevin Wayne. *Algorithms*. 4th. Addison-Wesley, 2011.

- [HS12] Maurice Herlihy and Nir Shavit. *The Art of Multiprocessor Programming*. Revised 1st. Morgan Kaufmann, 2012.
- [Str13] Bjarne Stroustrup. *The C++ Programming Language*. 4th. Addison-Wesley, 2013.
- [VJG17] David Vandevoorde, Nicolai M. Josuttis, and Douglas Gregor. *C++ Templates: The Complete Guide*. 2nd. Addison-Wesley, 2017.
- [Wil19] Anthony Williams. *C++ Concurrency in Action*. 2nd. Manning Publications, 2019.