

Nemes Tihamér 2 Sillabusz

A Nemes Tihamér NITV Programozás kategória, 2. korcsoport
anyagának kivonata

1 Verzió és státusz

Ez egy nem hivatalos javaslat a 2020/2021. tanévi Nemes Tihamér NITV Programozás kategória 2. korcsoportjának (9-10. osztályosok) második és harmadik fordulójában szereplő feladatok témaköreinek leírására.

Jelen verzió még szerkesztés alatt áll, nem teljes, és nem megosztásra szánt.

A Nemes Tihamér Sillabusz az IOI Syllabus mintájára készül, és jelenleg még fejlesztés alatt áll. Ha eléri célját, egy hivatalos dokumentum alakul ki belőle, amelynek aktuális verzióját a versenybizottság hagyja jóvá és teszi közzé minden évben. Az évek során a dokumentum változhat, fejlődhet.

2 Szerzők és elérhetőségeik

Szívesen fogadunk bármilyen visszajelzést és javaslatot a sillabusszal kapcsolatban a jelenlegi szerkesztő e-mail címére küldve (laszlo.nikhazy@gmail.com).

Azok számára, akik szeretnének hozzájárulni a dokumentum fejlesztéséhez, vagy hozzászólni, javaslatokat tenni a tartalmához, a sillabusz GitHub repository-jában található információk. Minden javaslatot, hozzászólást és segítséget szívesen fogadunk. <https://github.com/niklaci/NT-Syllabus>.

3 Introduction

During the years, the Syllabus has evolved. Currently it has the following purposes:

- It specifies a small set of required prerequisite knowledge. Below, this is given in the category “Included, unlimited” and to some extent also in “Included, to be defined”.
- It serves as a set of guidelines that help decide whether a task is suitable for the International Olympiad in Informatics (IOI). Based on this document, the International Scientific Committee (ISC) evaluates the task proposals when selecting the competition tasks.
- As a consequence of the previous item, another purpose of the Syllabus is to help the organizers of national olympiads prepare their students for the IOI.

The Syllabus aims to achieve these goals by providing a classification of topics and concepts from mathematics and computer science. More precisely, this Syllabus classifies each topic into one of six categories. Ordered by topic suitability, these are:

- ✓ Included, unlimited
- ✓📄 Included, to be defined
- ✓📄 Included, not for task description
- ? Outside of focus
- ✗🗑 Excluded, but open to discussion
- ✗ Explicitly excluded

In the next section we explain the scope of each category.

4 Categories

This Syllabus classifies a selection of topics into six different categories. Obviously, such a set of topics can never be exhaustive. Instead, the list given in this Syllabus should serve as examples that map out the boundary. Topics not explicitly mentioned in the Syllabus should be classified as follows:

- Anything that is a prerequisite of an Included topic is also Included.
- Anything that is an extension of an Excluded topic or similar to an Excluded topic is also Excluded.
- Anything else that is not mentioned in the Syllabus is considered Outside of focus.

Note that issues related to the usage of suitable terminology and notations in competition tasks are beyond the scope of this document.¹

If there is a particular topic for which you are not sure how it should be classified, we invite you to submit a clarification request to the current Syllabus maintainer.

Here are the definitions of the six possible classifications:

✓ Included, unlimited

Topics in this category are considered to be prerequisite knowledge. Contestants are expected to know them. These topics can appear in task descriptions without further clarification.

Example: *Integer* in §6.1

✓📖 Included, to be defined

Contestants should know this topic, but when it appears in a task description, the statement should contain a sufficient definition. This category is usually applied in situations where a general concept that would be ✓ has many different “flavors” and a formal definition is needed to distinguish among those.

Example: *Directed graph* in §6.2 DS2

✓📖 Included, not for task description

Topics that belong to this category should not appear in tasks descriptions. However, developing solutions and understanding model solutions may require the knowledge of these topics.

Example: *Asymptotic analysis of upper complexity bounds* in §5.2 AL1

Note: This is the main category that should be of interest when preparing contestants for the IOI. It should be noted that this set of topics contains a wide range of difficulties, starting from simple concepts and ending with topics that can appear in problems that aim to distinguish among the gold medallists. It is **not** expected that all contestants should know everything listed in this category.


? Outside of focus

Any topic that is not explicitly addressed by the Syllabus should be considered to belong to this category.

¹See T. Verhoeff: *Concepts, Terminology, and Notations for IOI Competition Tasks*, <http://scienceolympiads.org/ioi/sc/documents/terminology.pdf>

Contestants are not expected to have knowledge of these topics. Most competition tasks will not be related to any topics from this category.

However, this does not prevent the inclusion of a competition task that is related to a particular topic from this category. The ISC may wish to include such a competition task in order to broaden the scope of the IOI.

If such a task is considered for the IOI, the ISC will make sure that the task can reasonably be solved without prior knowledge of the particular topic, and that the task can be stated in terms of ✓ and ✓ concepts in a precise, concise, and clear way.

Examples of such tasks being used at recent IOIs include:

- Languages (a.k.a. Wikipedia) from IOI 2010 in Canada
- Odometer (a.k.a. robot with pebbles) from IOI 2012 in Italy
- Art class from IOI 2013 in Australia.

✕ Explicitly excluded

Some of the harder algorithmic topics are explicitly marked as excluded. It is guaranteed that there will not be a competition task that *requires* the contestants to know these areas.

Furthermore, the tasks will be set with the goal that knowledge of Excluded topics should not help in obtaining simpler solutions / solutions worth more points.

This category contains topics whose inclusion will result in problems that are unaccessible to a significant portion of IOI participants. This includes but is not limited to hard textbook algorithms and advanced areas in mathematics.

Still, note that the Syllabus must not be interpreted to restrict in any way the techniques that contestants are allowed to apply in solving the competition tasks.

Examples: *Calculus* in §6.3

✕🗨 Excluded, but open to discussion

As the Syllabus is a living document, there can be cases when we consider bringing in some of the Excluded topics. Usually, the topics in question are natural extensions of Included topics, or ones where drawing an exact boundary is difficult. Should such topics appear, they will be temporarily classified as “Excluded, but open to discussion”, and

by doing so we encourage all members of the IOI community to give us feedback on these topics.

The rest of this document contains the classification of topics.

5 Computing Science

5.1 Programming Fundamentals (PF)

PF1. Fundamental programming constructs(for abstract machines)

- ✓ Basic syntax and semantics of a higher-level language (at least one of the specific languages available at an IOI, as announced in the *Competition Rules* for that IOI)
- ✓ Variables, types, expressions, and assignment
- ✓ Simple I/O
- ✓ Conditional and iterative control structures
- ✓ Functions and parameter passing
- ✓📄 Structured decomposition

PF2. Algorithms and problem-solving

- ✓📄 Problem-solving strategies (understand–plan–do–check, separation of concerns, generalization, specialization, case distinction, working backwards, etc.)²
- ✓📄 The role of algorithms in the problem-solving process
- ✓📄 Implementation strategies for algorithms (also see §?? SE1)
- ✓📄 Debugging strategies (also see §?? SE3)
- ✓📄 The concept and properties of algorithms (correctness, efficiency)

PF3. Fundamental data structures

- ✓ Primitive types (boolean, signed/unsigned integer, character)
- ✓ Arrays (incl. multicolumn dimensional arrays)

²See G. Polya: *How to Solve It: A New Aspect of Mathematical Method*, Princeton Univ. Press, 1948

- ✓ Strings and string processing
- ✓📄 Static and stack allocation (elementary automatic memory management)
- ✓📄 Linked structures
- ✓📄 Implementation strategies for graphs and trees
- ✓📄 Strategies for choosing the right data structure
- ✓📄 Elementary use of real numbers in numerically stable tasks
- ✓📄 The floating-point representation of real numbers, the existence of precision issues.³
- ✓📄 Pointers and references

- ? Data representation in memory,
- ? Heap allocation,
- ? Runtime storage management,
- ? Using fractions to perform exact calculations.

- ✗ Non-trivial calculations on floating point numbers, manipulating precision errors

Regarding floating point numbers, there are well-known reasons why they should be, in general, avoided at the IOI.⁴ However, the currently used interface removes some of those issues. In particular, it should now be safe to use floating point numbers in some types of tasks – e.g., to compute some Euclidean distances and return the smallest one.

PF4. Recursion

- ✓ The concept of recursion
- ✓ Recursive mathematical functions
- ✓ Simple recursive procedures (incl. mutual recursion)
- ✓📄 Divide-and-conquer strategies
- ✓📄 Implementation of recursion
- ✓📄 Recursive backtracking

³Whenever possible, avoiding floating point computations completely is the preferred solution.

⁴See G. Horváth and T. Verhoeff: *Numerical Difficulties in Pre-University Education and Competitions*, Informatics in Education 2:21–38, 2003

PF5. Event-driven programming

Some competition tasks may involve a dialog with a reactive environment. Implementing such an interaction with the provided environment is ✓📄.

Everything not directly related to the implementation of reactive tasks is ?.

5.2 Algorithms and Complexity (AL)

We quote from the IEEE-CS Curriculum:

Algorithms are fundamental to computer science and software engineering. The real-world performance of any software system depends only on two things: (1) the algorithms chosen and (2) the suitability and efficiency of the various layers of implementation. Good algorithm design is therefore crucial for the performance of all software systems. Moreover, the study of algorithms provides insight into the intrinsic nature of the problem as well as possible solution techniques independent of programming language, programming paradigm, computer hardware, or any other implementation aspect.

AL1. Basic algorithmic analysis

- ✓📄 Algorithm specification, precondition, postcondition, correctness, invariants
- ✓📄 Asymptotic analysis of upper complexity bounds (informally if possible)
- ✓📄 Big O notation
- ✓📄 Standard complexity classes: constant, logarithmic, linear, $O(n \log n)$, quadratic, cubic, exponential, etc.
- ✓📄 Time and space tradeoffs in algorithms
- ✓📄 Empirical performance measurements.
- ? Identifying differences among best, average, and worst case behaviors,
- ? Little o, Omega, and Theta notation,
- ? Tuning parameters to reduce running time, memory consumption or other measures of performance
- ✗ Asymptotic analysis of average complexity bounds
- ✗ Using recurrence relations to analyze recursive algorithms

AL2. Algorithmic strategies

- ✓📖 Simple loop design strategies
- ✓📖 Brute-force algorithms (exhaustive search)
- ✓📖 Greedy algorithms
- ✓📖 Divide-and-conquer
- ✓📖 Backtracking (recursive and non-recursive), Branch-and-bound
- ✓📖 Dynamic programming⁵
- ? Heuristics
- ? Finding good features for machine learning tasks⁶
- ? Discrete approximation algorithms
- ? Randomized algorithms.
- ✗ Clustering algorithms (e.g. k -means, k -nearest neighbor)
- ✗ Minimizing multi-variate functions using numerical approaches.

AL3a. Algorithms

- ✓📖 Simple algorithms involving integers: radix conversion, Euclid's algorithm, primality test by $\mathcal{O}(\sqrt{n})$ trial division, Sieve of Eratosthenes, factorization (by trial division or a sieve), efficient exponentiation
- ✓📖 Simple operations on arbitrary precision integers (addition, subtraction, simple multiplication)⁷
- ✓📖 Simple array manipulation (filling, shifting, rotating, reversal, resizing, minimum/maximum, prefix sums, histogram, bucket sort)
- ✓📖 Simple string algorithms (e.g., naive substring search)
- ✓📖 sequential processing/search and binary search
- ✓📖 Quicksort and Quickselect to find the k -th smallest element.
- ✓📖 $\mathcal{O}(n \log n)$ worst-case sorting algorithms (heap sort, merge sort)
- ✓📖 Traversals of ordered trees (pre-, in-, and post-order)

⁵The IEEE-CS Curriculum puts this under AL8, but we believe it belongs here.

⁶E.g., finding a good way to classify images in the IOI 2013 Art class problem.

⁷The necessity to implement these operations should be obvious from the problem statement.

- ✓📄 Depth- and breadth-first traversals
- ✓📄 Applications of the depth-first traversal tree, such as topological ordering and Euler paths/cycles
- ✓📄 Finding connected components and transitive closures.
- ✓📄 Shortest-path algorithms (Dijkstra, Bellman-Ford, Floyd-Warshall)
- ✓📄 Minimum spanning tree (Jarník-Prim and Kruskal algorithms)
- ✓📄 $O(VE)$ time algorithm for computing maximum bipartite matching.
- ✓📄 Biconnectivity in undirected graphs (bridges, articulation points).
- ✓📄 Connectivity in directed graphs (strongly connected components).
- ✓📄 Basics of combinatorial game theory, winning and losing positions, minimax algorithm for optimal game playing
- ✗❓ Maximum flow. Flow/cut duality theorem.
- ✗ Optimization problems that are easiest to analyze using matroid theory. Problems based on matroid intersecions (except for bipartite matching).
- ✗ Lexicographical BFS, maximum adjacency search and their properties

AL3b. Data structures

- ✓📄 Stacks and queues
- ✓📄 Representations of graphs (adjacency lists, adjacency matrix)
- ✓📄 Binary heap data structures
- ✓📄 Representation of disjoint sets: the Union-Find data structure.
- ✓📄 Statically balanced binary search trees. Instances of this include binary index trees (also known as Fenwick trees) and segment trees (also known as interval trees and tournament trees).⁸

⁸Not to be confused with similarly-named data structures used in computational geometry.

- ✓📄 Balanced binary search trees⁹
- ✓📄 Augmented binary search trees
- ✓📄 $O(\log n)$ time algorithms for answering lowest common ancestor queries in a static rooted tree.¹⁰
- ✓📄 Creating persistent data structures by path copying.
- ✓📄 Nesting of data structures, such as having a sequence of sets.
- ✓📄 Tries

- ✗❓ String algorithms and data structures: there is evidence that the inter-reducibility between KMP, Rabin-Karp hashing, suffix arrays/tree, suffix automaton, and Aho-Corasick makes them difficult to separate.
- ✗❓ Heavy-light decomposition and separator structures for static trees.
- ✗❓ Data structures for dynamically changing trees and their use in graph algorithms.

- ✗ Complex heap variants such as binomial and Fibonacci heaps,
- ✗ Using and implementing hash tables (incl. strategies to resolve collisions)
- ✗ Two-dimensional tree-like data structures (such as a 2D statically balanced binary tree or a treap of treaps) used for 2D queries.
- ✗ Fat nodes and other more complicated ways of implementing persistent data structures.

AL4. Distributed algorithms

This entire section is **?**.

AL5. Basic computability

All topics related to computability are **✗**. This includes the following: Tractable and intractable problems; Uncomputable

⁹Problems will not be designed to distinguish between the implementation of BBSTs, such as treaps, splay trees, AVL trees, or scapegoat trees

¹⁰Once again, different implementations meeting this requirement will not be distinguished.

functions; The halting problem; Implications of uncomputability.

However, see AL7 for basic computational models.

AL6. The complexity classes P and NP

Topics related to non-determinism, proofs of NP-hardness (reductions), and everything related is **X**.

Note that this section only covers the results usually contained in undergraduate and graduate courses on formal languages and computational complexity. The classification of these topics as **X** does not mean that an NP-hard problem cannot appear at an IOI.

AL7. Automata and grammars

- ✓📄 Understanding a simple grammar in Backus-Naur form
- ? Formal definition and properties of finite-state machines,
- ? Context-free grammars and related rewriting systems,
- ? Regular expressions
- X Properties other than the fact that automata are graphs and that grammars have parse trees.

AL8. Advanced algorithmic analysis

- ✓📄 Amortized analysis.
- ? Online algorithms
- ? Randomized algorithms
- X Alpha-beta pruning

AL9. Cryptographic algorithms

This entire section is **?**.

AL10. Geometric algorithms

In general, the ISC has a strong preference towards problems that can be solved using integer arithmetics to avoid precision issues. This may include representing some computed values as exact fractions, but extensive use of such fractions in calculations is discouraged.

Additionally, if a problem uses two-dimensional objects, the ISC prefers problems in which such objects are rectilinear.

- ✓📄 Representing points, vectors, lines, line segments.
- ✓📄 Checking for collinear points, parallel/orthogonal vectors and clockwise turns (for example, by using dot products and cross products).
- ✓📄 Intersection of two lines.
- ✓📄 Computing the area of a polygon from the coordinates of its vertices.¹¹
- ✓📄 Checking whether a (general/convex) polygon contains a point.
- ✓📄 Coordinate compression.
- ✓📄 $\mathcal{O}(n \log n)$ time algorithms for convex hull
- ✓📄 Sweeping line method
- ✗ Point-line duality
- ✗ Halfspace intersection, Voronoi diagrams, Delaunay triangulations.
- ✗ Computing coordinates of circle intersections against lines and circles.
- ✗ Linear programming in 3 or more dimensions and its geometric interpretations.
- ✗ Center of mass of a 2D object.
- ✗ Computing and representing the composition of geometric transformations if the knowledge of linear algebra gives an advantage.

AL11. Parallel algorithms

This entire section is **?**.

¹¹The recommended way of doing so is to use cross products or an equivalent formula.
 TODO url

6 Mathematics

6.1 Arithmetics and Geometry

- ✓ Integers, operations (incl. exponentiation), comparison
- ✓ Basic properties of integers (sign, parity, divisibility)
- ✓ Basic modular arithmetic: addition, subtraction, multiplication
- ✓📄 Prime numbers
- ✓ Fractions, percentages
- ✓ Line, line segment, angle, triangle, rectangle, square, circle
- ✓ Point, vector, coordinates in the plane
- ✓ Polygon (vertex, side/edge, simple, convex, inside, area)
- ✓📄 Euclidean distances
- ✓📄 Pythagorean theorem
- ✗❓ Additional topics from number theory.
- ✗ geometry in 3D or higher dimensional spaces
- ✗ analyzing and increasing precision of floating-point computations
- ✗ modular division and inverse elements
- ✗ complex numbers,
- ✗ general conics (parabolas, hyperbolas, ellipses)
- ✗ trigonometric functions

6.2 Discrete Structures (DS)

DS1. Functions, relations, and sets

- ✓📄 Functions (surjections, injections, inverses, composition)
- ✓📄 Relations (reflexivity, symmetry, transitivity, equivalence relations, total/linear order relations, lexicographic order)
- ✓📄 Sets (inclusion/exclusion, complements, Cartesian products, power sets)
- ✗ Cardinality and countability (of infinite sets)

DS2. Basic logic

- ✓ First-order logic
- ✓ Logical connectives (incl. their basic properties)
- ✓ Truth tables
- ✓ Universal and existential quantification (Note: statements should avoid definitions with nested quantifiers whenever possible.)
- ✓☞ Modus ponens and modus tollens
- ?
- ?
- ✗ Validity
- ✗ Limitations of predicate logic

DS3. Proof techniques

- ✓☞ Notions of implication, converse, inverse, contrapositive, negation, and contradiction
- ✓☞ Direct proofs, proofs by: counterexample, contraposition, contradiction
- ✓☞ Mathematical induction
- ✓☞ Strong induction (also known as complete induction)
- ✓ Recursive mathematical definitions (incl. mutually recursive definitions)

DS4. Basics of counting

- ✓ Counting arguments (sum and product rule, arithmetic and geometric progressions, Fibonacci numbers)
- ✓☞ Permutations and combinations (basic definitions)
- ✓☞ Factorial function, binomial coefficients
- ✓☞ Inclusion-exclusion principle
- ✓☞ Pigeonhole principle
- ✓☞ Pascal's identity, Binomial theorem
- ?
- ✗ Solving of recurrence relations
- ✗ Burnside lemma

DS5. Graphs and trees

- ✓📄 Trees and their basic properties, rooted trees
- ✓📄 Undirected graphs (degree, path, cycle, connectedness, Euler/Hamilton path/cycle, handshaking lemma)
- ✓📄 Directed graphs (in-degree, out-degree, directed path/cycle, Euler/Hamilton path/cycle)
- ✓📄 Spanning trees
- ✓📄 Traversal strategies
- ✓📄 ‘Decorated’ graphs with edge/node labels, weights, colors
- ✓📄 Multigraphs, graphs with self-loops
- ✓📄 Bipartite graphs
- ✓📄 Planar graphs

- ✗ Hypergraphs
- ✗ Specific graph classes such as perfect graphs
- ✗ Structural parameters such as treewidth and expansion
- ✗ Planarity testing
- ✗ Finding separators for planar graphs

DS6. Discrete probability

Applications where everything is finite (and thus arguments about probability can be easily turned into combinatorial arguments) are **?**, everything more complicated is **✗**.

6.3 Other Areas in Mathematics

- ✗ Geometry in three or more dimensions.
- ✗ Linear algebra, including (but not limited to):
 - Matrix multiplication, exponentiation, inversion, and Gaussian elimination
 - Fast Fourier transform
- ✗ Calculus
- ✗ Theory of combinatorial games, e.g., NIM game, Sprague-Grundy theory
- ✗ Statistics