

Entrance Exam Questions 2021

01.04.02 Applied Mathematics and Informatics

Master's program "Bioinformatics and Systems Biology"

ITMO University

**At the entrance exam a student chooses one of the two specializations and gets two questions (one biological and one computational) from the corresponding question list.*

Specialization 1. Data Analysis in Biology and Medicine

1. Biology

1. General features of prokaryotic and eukaryotic cells structure and functioning.
2. Catabolism and biosynthesis. Their coordination. Cellular respiration. Photosynthesis. Carbon fixation, C4 and C3 photosynthesis.
3. Structure and function of DNA. Chromosomal DNA and its packaging. Global structure of chromosomes.
4. Human genome. Genome sequencing projects. Population genetics.
5. Epigenetics. Histone modifications. Non-coding RNAs, their functions. Riboswitches. Aptamers.
6. DNA replication in prokaryotes and eukaryotes. DNA polymerases.
7. Transcription in prokaryotes and eukaryotes. Types of eukaryotic RNA polymerases. Transcription factors.
8. mRNA maturation. Splicing. Nonsense-mediated decay. Trans-splicing, self-splicing introns.
9. Translation in prokaryotes and eukaryotes. Ribosome. Translation factors. Folding and chaperons. Post-translational modifications of proteins.
10. Cell membrane. Composition of the membrane. Membrane proteins. Membrane rafts.
11. Principles of membrane transport. Carrier proteins and active membrane transport. Ion channels.
12. Genetic engineering tools. Restriction enzymes. Genome editing.
13. General principles of cell signaling. Main signaling pathways and molecules.
14. Types of immunity. Organs and cells of the immune system. Antibodies. Vaccines.
15. DNA repair. Components of the cell-cycle control systems. Intracellular control of cell-cycle events. Programmed cell death (apoptosis).

2.1. Mathematics

1. Prime and composite numbers. Divisibility. Infinitude of primes. Fundamental theorem of arithmetics. Greatest common denominator and lowest common multiple.
2. Degree with a rational exponent. Exponential function. Logarithm. Its definition and properties.
3. Trigonometric functions. Their definitions and properties. Vector and scalar product in two-dimensional and three-dimensional space.
4. Principle of mathematical induction. Bernoulli inequality. Arithmetical and geometrical progressions, general term formula and sum formula.
5. Polynomials in one variable. Vieta's formulas. Number of roots of a polynomial.

2.2. Programming in Python

1. Python Interpreter. Using Python interactively. Running Python programs.
2. Numbers. Operations with integers. Operations with real numbers. Comparison operations
3. Strings. Subsetting. Searching for substrings. Lists.
4. Conditional operator. Logical operations. Loops.
5. Functions. Defining and calling functions. Recursive functions. Examples.

2.3. Linux platform

1. Running executable files from the terminal. Input/output. Input/output redirection.
2. Navigating file system. List files in directory, changing directories, creating directories.
3. Working with files from the terminal. Copying, moving, deleting files. Displaying contents with cat, less, head, tail.
4. File search. Examples of using find and grep tools.
5. Remote access with ssh. Running commands remotely. Copying files to and from remote servers. Scp command.

Recommended reading:

Biology:

- Alberts B., Johnson A., Lewis J., Raff M., Roberts K., Walter P. Molecular Biology of the Cell. Garland Sciences; edition V or higher. (or Alberts B., Bray D., et al. Essential Cell Biology. Garland Sciences; edition III or higher).
- Krebs J.E., Goldstein E.S., Kilpatrick S.T. Lewin's Genes. Jones & Bartlett Learning; edition X or higher.
- Nelson D.L., Cox M.M. Lehninger's Principles of Biochemistry. W.H. Freeman Publishing, edition V or higher.
- Thomas D. Pollard Cell Biology.

Mathematics, Python and Linux:

- <https://www.khanacademy.org/math>
- <https://docs.python.org/3/tutorial/>
- <https://developers.google.com/edu/python/>
- <https://www.codecademy.com/learn/learn-python/>
- <https://www.digitalocean.com/community/tutorials/an-introduction-to-linux-basics>
- <https://www.digitalocean.com/community/tutorials/an-introduction-to-the-linux-terminal>
- <https://www.codecademy.com/learn/learn-the-command-line>
- Sander van Vugt, Beginning the Linux Command Line

Specialization 2. Algorithmic Bioinformatics

1. Biology

1. Biology foundations. Important molecules for biology. Water and life. pH, acids and bases.
2. Body structure and homeostasis. Organ systems. Cell and tissue types.
3. Cells. Basic cell structures. The cell membrane. Eukaryotic cell structures. Prokaryotes and eukaryotes. Plant and animal cells.
4. Muscle types, skeletal muscles. Energy and transport. Metabolism. Enzymes. Passive and active transport. Osmosis and tonicity.
5. Reproduction and cell division. Types of reproduction. The cell cycle and mitosis. Meiosis. Fertilization and development.
6. Chromosome structure and numbers. Levels of chromatin structure.
7. Mendel's experiments, Mendel's laws, dominant and recessive alleles. Mendelian inheritance, deviations from mendelian inheritance. Sex linkage.
8. Gene interaction. Epistasis, complementation, polymery, pleiotropy.
9. Molecular genetics. DNA structure and replication. RNA and protein synthesis. Biotechnology.
10. Human genome. Genome sequencing projects (1k human genomes, VGP).
11. Evolution and natural selection. Evidence of evolution. Phylogeny. Artificial selection.
12. Biological classification, binary nomenclature. Phylogenetic classification. Three-domain system of life.
13. Respiratory and circulatory system. Cellular respiration. Gas exchange in lungs.
14. Plant cells and differences from animal cells. Plant body structure. Photosynthesis.
15. Types of immunity. Organs and cells of the immune system. Antibodies. Vaccines.

2. Mathematics and programming

(Each question contains a theoretical and practical part. The practical part consists of writing a small program in a compiled programming language (preferably, C++ or Java) that reads some input from file, carries out the specified actions, and prints the required output to file. Applicant is expected to answer the questions about the implementation, in particular about the algorithm asymptotic complexity)

1. Elementary functions of one variable. Continuity and differentiability. Graphs of functions, extrema, convexity, etc.
 - Practical task: write a program to find a root of a given monotonic function.
2. Single variable integrals and derivatives: definitions, properties, main techniques.
 - Practical task: write a program to find the area under the graph of a given function.
3. Linear operators and matrices. Eigenvectors and eigenvalues.
 - Practical task: write a program to raise matrix to power using exponentiation by squaring approach.
4. The principle of mathematical induction. Series (arithmetic progression, geometric progression, square pyramidal numbers, etc). Recurrence relations (Fibonacci numbers, binomial coefficients, etc).
 - Practical task: write a program implementing insertion sort algorithm.
5. Probability space. Independent events, conditional probability, Bayes theorem. Definition of a random variable. Discrete and continuous random variables. Probability mass function. Cumulative distribution function. Probability density function.

- Practical task: write a program to estimate the area under the graph of a given function using Monte Carlo approach.
6. Bernoulli trials and related distributions, Poisson distribution, Uniform distribution, Gaussian distribution. Central limit theorem. Mean, median, mode. Variance, standard deviation.
- Practical task: write a program to calculate exactly the moments of a given discrete distribution.

Recommended reading:

Biology:

- <https://www.khanacademy.org/science/high-school-biology>
- <https://ocw.mit.edu/courses/biology/7-012-introduction-to-biology-fall-2004/video-lectures/>

Mathematics:

- Graham R., Knuth D., Patashnik O. Concrete Mathematics: A Foundation for Computer Science.
- Diez D.M., Cetinkaya-Rundel M., Barr C.D. OpenIntro Statistics. Fourth edition. OpenIntro, 2019.
- <https://www.coursera.org/specializations/statistic>