LIFE SCIENCES (Computational Biology)

Programme Code: LIFE24

Programme Outcome:

- A thorough training in mathematical, physical and computational methods in modern biology.
- Exposure to all aspects of modern biology via coursework and seminars.
- Research in cutting-edge, relevant areas of biology and biomedicine.

DETAILED COURSE STRUCTURE

Sr. No	Course Code	Subject Title	Hours	Credits
1	10-LIFE24-601-C	Basic Biology	30	2
2	10-LIFE24-603-C	Mathematics and Statistics for Biologist	30	2
3	10-LIFE24-604-C	Physical Methods for Biologists	30	2
4	10-LIFE24-606-C	Biological Sequence Analysis	30	2
5	10-LIFE24-607-C	Systems Biology	30	2
6	10-LIFE24-608-C	Research Methodology	40	2
7	10-LIFE24-609-C	Project	60	4
8	10-LIFE24-601-E	Biophysics of Macromolecular Structures	30	2
9	10-LIFE24-602-E	Simulation Techniques in Biology	30	2
10	10-LIFE24-603-E	Population Biology, Ecology and Evolution	30	2
11	10-LIFE24-604-E	Computational Neuroscience	30	2
12	10-LIFE24-605-E	Modeling of Infectious Diseases	30	2
13	10-LIFE24-606-E	Next-generation sequencing: Technologies, algorithms, applications	30	2
14	10-LIFE24-607-E	Machine Learning	30	2

SUMMARY

	Course	Quantity	Hours	Credits
1	Core Courses	5 Nos.	**150**	**10**
2	Research Methodology	1 No.	**40**	**2**
3	Project	1 No.	**60**	**4**
4	Elective Courses	1 No.	**30**	**2**
Total Hours and Credits			**280 h**	**18**

* In addition, courses offered by other CIs/OCCs/NPTEL/Swayam and Institutes and Universities having MoUs with HBNI may be opted.

C: Core courses

E: Elective Courses

COORDINATORS

Program Coordinators:

Dr. Rahul Siddharthan (E-Mail: rsidd@imsc.res.in)
Dr. Sitabhra Sinha [Dean, Computational Biology, IMSc] (E-mail: sitabhra@imsc.res.in)

Course coordinators:

Course	Coordinators	Contact
Basic Biology	Areejit Samal	asamal@imsc.res.in
Mathematics and Statistics for Biologist	Sandeep Choubey	sandeep@imsc.res.in
Physical Methods for Biologists	Sitabhra Sinha	sitabhra@imsc.res.in
Biological Sequence Analysis	Rahul Siddharthan	rsidd@imsc.res.in
Systems Biology	Sitabhra Sinha	sitabhra@imsc.res.in
Research Methodology	Sandeep Choubey	sandeep@imsc.res.in
Project	Sitabhra Sinha (dean)	sitabhra@imsc.res.in
Biophysics of Macromolecular Structures	Vani Vemparala	vani@imsc.res.in
Simulation Techniques in Biology	Vani Vemparala	vani@imsc.res.in
Population Biology, Ecology and Evolution	Sitabhra Sinha	sitabhra@imsc.res.in
Computational Neuroscience	Sitabhra Sinha	sitabhra@imsc.res.in
Modeling of Infectious Diseases	Sitabhra Sinha	sitabhra@imsc.res.in
Next-generation sequencing: Technologies, algorithms, applications	Areejit Samal	asamal@imsc.res.in
Machine Learning	Rahul Siddharthan	rsidd@imsc.res.in

COURSES

10-LIFE24-601-C: Basic Biology (30 Lecture Hrs)

Coordinators: Areejit Samal (asamal@imsc.res.in)

Course Details:

- ✓ **Basic molecular biology**

Biomolecules, DNA, RNA, proteins; genetic code; "central dogma"; gene transcription, translation; packaging of DNA in eukaryotes; Transcriptional regulation, miRNA and RNAi, introns/exons, splicing DNA packaging, heterochromatin and euchromatin, methylation, histone tail modifications, noncoding RNA and gene regulation.

- ✓ **Cell biology**

Cellular metabolism, cell motility, cytoskeleton, intracellular transport, membrane transport, channels, receptors, signalling, cell cycle

- ✓ **Genetics**

Mendelian genetics, definitions (genes, loci, alleles), dominance; replication, mitosis/meiosis, linkage/crossover

- ✓ **Developmental biology**

Differentiation, early development of drosophila via gradients, gap and pair-rule genes, role of hox genes, Williston's "law", other organisms, Waddington's canalization

- ✓ **Evolutionary biology**

Molecular evolution, evolution of DNA, genes, proteins and regulation. Molecular mechanisms of evolution -- mutation, recombination, duplication, mobile elements

- ✓ **Basics of neuroscience and ecology**

Neurons, synapses, neural architecture in various organisms, action potential, Hodgkin-Huxley equation, Ecology and evolution, ecosystems, food webs

- ✓ **Experimental techniques**

PCR, southern/northern/western blots, chromatin immunoprecipitation, microarrays, high-throughput sequencing, ChIP-chip and ChIP-seq, high-resolution microscopy (fluorescence imaging, confocal, FRET, PALM etc), GFP and reporter gene assays.

- ✓ **Protein Structure**

Taxonomy: Primary, Secondary and tertiary structure, fold types Protein folding: The Anfinsen experiments, Protein database (PDB), Helix-helix packing in globular proteins, Beta-sheet packing, Folding pathways, thermal denaturation, partially folded intermediates, misfolding and aggregation.

- ✓ **Immunology**

Innate and adaptive immunity - Key players of the immune system: T cells, B cells et al - specificity and cross-reactivity in ligand-receptor (antigen-antibody) interactions - kinetic proofreading for antigenic discrimination - Cell-cell communication and cytokinesigaling - Cell fate: hematopoiesis differentiation tree - Immune repertoire: thymic selection and clonal size distribution - Population dynamics: intracellular (lymphocytes) and species- evel(host-pathogen)

- ✓ **Other topics**

Basics of: Intercellular communication, epidemiology, physiology

Course Outcome:

Students will know the essentials of biology concepts, lab techniques, research areas of interest in modern biology, and will be able to discuss with and collaborate with experimental biologists in a variety of areas.

References:

1. Alberts, B., Heald, R., Johnson, A., Morgan, D., Raff, M., Roberts, K., & Walter, P. (2022). Molecular biology of the cell: seventh international student edition with registration card. WW Norton & Company.
2. Watson, J. D. (2004). Molecular biology of the gene. Pearson Education India.
3. Lodish, H. F. (2008). Molecular cell biology. Macmillan.
4. Hartwell, L., Goldberg, M. L., Fischer, J. A., Hood, L. E., & Aquadro, C. F. (2018). Genetics: from genes to genomes (p. 960). New York, NY, USA: McGraw-Hill Education.
5. Nelson, D. L. (2008). Lehninger principles of biochemistry: Macmillan. Lehninger principles of biochemistry: Macmillan.

10-LIFE24-603-C: Mathematics And Statistics For Biologists (30 Lecture Hrs)

Coordinators: Sandeep Choubey (sandeep@imsc.res.in)

Course Details:

✓ **Differential equations**

Introduction to ODEs and PDEs, linear and non-linear, properties, how to solve analytically and numerically; examples -- Hodgkin-Huxley, reaction-diffusion equations, Volterra equations.

✓ **Essentials of linear algebra**

Vectors, matrices, eigenvalues and eigenvectors; orthogonal bases of functions, Sturm-Liouville theory and differential equations; Fourier series and Fourier transforms.

✓ **Probability theory and statistics**

Basic concepts -- random variables, mean, variance, moments; conditional probabilities, hypothesis and data, likelihood, Bayes' theorem; probability distributions -- binomial, multinomial, Poisson, normal; the central limit theorem; hypothesis testing, significance testing (orthodox and Bayesian methods); parameter estimation.

✓ **Simulations**

Introduction to Markov Chain Monte Carlo for exploring space of hypotheses: ergodicity, detailed balance, convergence. Metropolis and Gibbs sampling.

✓ **Machine learning**

Decision tree learning, artificial neural networks, support vector machines, Bayesian learning and Bayesian networks.

✓ **Other topics**

Game theory, applications to evolutionary biology, agent-based modelling of complex systems

Course Outcome:

Students will know essential mathematical techniques of calculus, linear algebra, modelling of biosystems, statistical analysis and more.

References:

1. Nonlinear Dynamics and Chaos, Steven H Strogatz
2. A First Course in Probability by Sheldon Ross
3. Introduction to Probability models by Sheldon Ross
4. Stochastic Processes in Physics and Chemistry by N. G. Van Kampen,
5. Linear Algebra and Its Applications by David C. Lay, Steven Lay and Judi McDonald
6. Data Analysis: A Bayesian Tutorial by D. S. Sivia and J. Skilling

10-LIFE24-604-C: Physical Methods For Biologists (30 Lecture Hrs)

Coordinators: Sitabhra Sinha (sitabhra@imsc.res.in)

Course Details:

✓ **Basic physics of soft matter**

Length scales and time scales in biological matter, self-organization and self-assembly, illustrative examples - DNA, microtubules and/or actin and lipid membranes, coarse-grained representations, interactions and bonding including van der Waals forces, hydrogen bonding, electrostatics and screening, what can be measured, energy scales.

✓ **Thermodynamics and statistical mechanics**

Thermal equilibrium, entropy, laws of thermodynamics, free energies, different ensembles and relation to computational biology examples, Boltzmann distribution, harmonic oscillator, equipartition theorem, virial theorem, thermodynamics of self-assembly, simple ideas of phase transitions.

✓ **Noise, diffusion and drift**

Thermal fluctuations and noise, random walk, diffusion equation as continuum limit of the random walk, probability density, continuity equation, Fick's law, drift-diffusion equation, Stokes-Einstein formula, example of receptor clustering.

✓ **Mechanics of continuous media**

Elasticity of isotropic solids, estimates for elastic constants of biological materials, fluids in biology, basics of fluid mechanics, Pascal's law, Euler's equation, viscosity, Reynolds number, Navier-Stokes's equation, flow through narrow pipes, dimensionless groups, swimming of microorganisms, hydrodynamic interactions, introduction to viscoelasticity.

✓ **Polymers, membranes and gels**

Simple ideas of polymers and membranes, polymer elasticity, polymer dynamics qualitative discussion, scaling ideas in polymers, semi-flexibility, membrane elasticity, membrane fluctuations, passive gels.

✓ **Out of equilibrium**

Active matter, simple examples, what do we need to model them, polymerization forces, cell streaming, molecular motors and models, active gels.

✓ **Other topics**

Interfacial tension in biological systems, Laplace pressure, wetting and spreading, osmotic effects, capillary effects in biology, micro-rheology for biological systems.

Course Outcome:

Students will know basic biophysics of soft matter, basics of thermodynamics, statistical mechanics, diffusion, noise, polymer and protein biophysics.

Reference:

1. Physical Biology of the Cell, by Rob Phillips, Jane Kondev, Julie Theriot and Hernan G. Garcia
2. Cell Biology by the Numbers, by Ron Milo and Rob Phillips
3. Random Walks in Biology, by Howard C. Berg
4. Why Size Matters: From Bacteria to Blue Whales, by John Tyler Bonner
5. Polymer Physics, by Michael Rubinstein and Ralph H. Colby
6. Biophysics: Searching for Principles, by William Bialek
7. So Simple a Beginning: How Four Physical Principles Shape Our Living World, by Raghuveer Parthasarathy

10-LIFE24-606-C: Biological Sequence Analysis (30 Lecture Hrs)

Coordinators: Rahul Siddharthan (rsidd@imsc.res.in)

Course Details:

- ✓ **Biomolecules**
  Basics (DNA, RNA, proteins)
- ✓ **Probability theory**
  Basic laws -- joint probabilities, conditional probabilities, likelihood, Bayes' theorem
- ✓ **String algorithms**
  Finding common substrings and subsequences: Boyer-Moore algorithm, suffix trees, finding strings with mismatches.
- ✓ **Sequence alignment**
  Algorithms for pairwise and multiple sequence alignment -- scoring model, Needleman-Wunsch and Smith-Waterman algorithms, BLAST and other heuristic algorithms, significance of scores, structural alignment.
- ✓ **Sequence assembly**
  Assembling short reads, with and without scaffold; ChIP-seq algorithms.
- ✓ **Markov models**
  Markov chains, hidden Markov models, Baum-Welch and Viterbi algorithms, profile HMMs and software (HMMer, etc)
- ✓ **Transcriptional regulation**
  Transcription factor binding sites, position weight matrices, sequence logos, motif-finding via expectation maximisation (MEME) and Gibbs sampling.
- ✓ **Phylogenetic trees**
  Building a tree from pairwise distances, neighbour-joining, parsimony
- ✓ **Proteins: Structural characterization**
  X-ray crystallization, circular dichroism, spectroscopy, NMR, single molecule experiments
- ✓ **Proteins: Homology modelling**
  Homology Modeling, Visualization

Course Outcome:

Students will have an exposure to bioinformatic algorithms applied to a variety of problems, from sequence alignment to motif finding to phylogenetics to sequence assembly and graph algorithms.

Reference:

1.Durbin, Eddy, Krogh, Mitchison, "Biological Sequence Analysis"
2.Compeau, Pevzner, "Bioinformatics Algorithms"
3. Literature

10-LIFE24-607-C: Systems Biology (30 Lecture Hrs)

Coordinators: Sitabhra Sinha (sitabhra@imsc.res.in)

Course Details:

✓ **Networks in biology**

- The diversity of networks across space and time in biological systems
- Intra-cellular networks: The gene network and protein-protein interaction network
- Intra-cellular networks: The metabolic network
- Intra-cellular networks: signaling networks - pathways and enzyme-substrate reaction cascades
- The signaling network coordination of immune response to infection
- Reconstructing biological networks from lab experiments
- Structural analysis of networks: Global properties
- Structural analysis of networks: Motifs and Modules
- Dynamics on biological networks: Modeling signaling pathways
- Inter-cellular networks: Neuronal networks
- Inter-organism networks: Contact structure and contagion propagation
- Inter-species networks: Stability-instability of food webs

✓ **Patterns in Biology**

- Temporal patterns: Biological clocks and circadian rhythms
- Oscillatory activity in Pancreatic beta cells and insulin secretion
- Pattern formation during development
- Development in Drosophila
- Development of the vertebrate body plan
- Modeling developmental patterns: Reaction-diffusion models and Turing Patterns
- Spatial patterns: Linear stability analysis and Fourier modes
- Autocatalysis and lateral inhibition: Gierer-Meinhardt and related pattern generation mechanisms in biosystems, center-surround principle in retina and cortex
- Modeling genesis of functional patterns: Ocular dominance columns
- Development of plants and L-systems modeling
- Cell differentiation and Random NK Boolean Networks
- Morphogenesis
- Fractals in biology: Examples (1/f noise, circulation system), characterization
- Fractals in biology: Generation mechanisms

✓ **Waves in biology**

- Importance of waves in biology for communication and coordination
- Intra-cellular waves: Calcium waves, targets and spirals
- Inter-cellular waves: Waves in the brain, heart and uterus
- Excitable media models of physiological systems
- Ionic basis of excitation: Hodgkin-Huxley formalism
- Simple and complex models of excitability
- Excitability, Oscillatory and Bistability regimes of systems
- Wave propagation through inter-cellular gap junctions: Diffusion approximation
- Genesis and dynamics of spiral waves: kinematic approach

- Nonlinear dynamical aspects of spiral waves: Restitution and dispersion
- Excitation-contraction coupling and the role of organ structure in wave dynamics
- Bidomain models of biological electrical activity
- Waves in single populations: Fisher waves
- Waves in interacting populations: Propagating epidemics, spiral waves in host-parasite spatial dynamics

Course Outcome:

Students will be familiar with concepts of systems biology including biological networks, patterns and pattern formation, waves in biology, and modelling biosystems as complex dynamical systems.

References:

1. Alon, U. (2019). An introduction to systems biology: design principles of biological circuits. Chapman and Hall/CRC.
2. Palsson, B. Ø. (2006). Systems biology: properties of reconstructed networks. Cambridge university press.
3. Newman, M. (2018). Networks. Oxford university press.
4. Barabási, A. L. (2016). Network science. Cambridge University Press.
5. Murray, J.D. (1989) Mathematical Biology. Springer.
6. Epstein, I. and Pojman, J. A. (1998) An Introduction to Nonlinear Chemical Dynamics. Oxford University Press.
7. Ball, P. (2009) Nature's Patterns. Oxford University Press.
8. Sinha, S. and Sridhar S. (2015) Patterns in Excitable Media. CRC Press.

ELECTIVE COURSES

10-LIFE24-601-E: Biophysics Of Macromolecular Structures (30 Lecture Hrs)

Coordinators: Vani Vemparala
(vani@imsc.res.in)

Course Details:

- ✓ **Structure and Biophysics of Biomolecules**
  Introduction to macromolecular chemistry, building blocks for macromolecular structures, biophysical methods for structure analysis, nucleic acid structure, protein-nucleic acid interactions, membrane proteins, microtubules and other supramolecular assemblies, investigative methods from the atomic to cellular levels, including X-ray crystallography, NMR spectroscopy, molecular dynamics, electron and light microscopy, AFM, single molecule techniques and simulations.
- ✓ **Kinetics**
  Chemical kinetics and application to dynamical processes in proteins, self assembly processes, classical kinetics, transition state theory, unimolecular decomposition, potential energy surfaces, scattering processes and photodissociation processes, enzyme kinetics.
- ✓ **Biophysical approaches to Biopolymers**
  Basics of polymers, protein folding problem, protein aggregation, DNA, DNA electrostatics, DNA force extension relations, RNA folding, polymerization, polymerization forces, dynamic instability, tread-milling and their physical description.
- ✓ **Biophysical Approaches to Membranes**
  Lipids and Membranes: Structure of various cell membranes, surface tension and curvature energies, Helfrich theory, clustering, phase separation, nanoscale structures, i.e., rafts, multicomponent membranes.
- ✓ **SPECIAL TOPICS**
  Kinetics and statistical mechanics of helix coil transitions; physical approaches to the refolding and assembly of multi-subunit proteins; fluorescence spectroscopic studies of macromolecules, molecular basis of enzyme catalysis, antibody structure and function, virus structure and assembly.

Course outcome:

Students will know about biomolecular structure, experimental techniques for structure determination, and computer studies and simulations, applied to proteins, RNA, membranes and other biomolecules.

References:

1. Understanding Molecular Simulation: From Algorithms to Applications by Berend Smit and Daan Frenkel
2. Molecular Modeling and Simulation by Tamar Schlick

7) 10-LIFE24-602-E: Simulation Techniques In Biology (30 Lecture Hrs)

Coordinators: Vani Vemparala
(vani@imsc.res.in)

Course Details

- ✓ **Molecular Dynamics**
  Introduction to MD and applications in biology and drug design; Basic Statistical mechanics: Basic thermodynamics, Ensembles (microcanonical, canonical, grand canonical, isothermal-isobaric), Virial theorem, Nose-Hoover chains; Forcefields and interaction potential: Many body potentials, Born-Oppenheimer approximation, electrostatic interactions including Ewald sum, interaction potential for organic molecules; popular forcefields: AMBER, CHARMM, OPLS etc.,;Integration methods and Liouville time operators Phase space concepts, Liouville theorem, Equilibrium solution of Liouville equation, Trotter factorization; Integration algorithms: Verlet, Velocity-Verlet, Gear-Predictor, multiple-time step algorithm, holonomic constraints (RATTLE/SHAKE).
- ✓ **Monte Carlo Simulations**
  Importance Sampling, Random variables and stochastic processes,lattice models, Random walks, Gibbs sampling, sampling errors, configurational-bias Monte Carlo method, Markov chain Monte Carlo, Advanced Monte Carlo methods: Parallel tempering, simulated annealing
- ✓ **Reaction Diffusion**
  Predator Prey Models, Reaction Kinetics, diffusion-limited reactions, Population dynamics, Reaction-diffusion Equations
- ✓ **Brownian/Stochastic simulations**
  Stochastic reaction-diffusion models:Compartment-based reaction-diffusion algorithm, reaction-diffusion master equation, pattern formation; Diffusion: Brownian motion, On/Off-Lattice models, diffusion to adsorbing surfaces, reactive boundary conditions, Einstein-Smoluchowski relation; Stochastic models of transport processes in cells: Fokker Planck Equations, Brownian ratchet models, Chapman Kolmogorov equation, Gillespie algorithm, chemical master equation.
- ✓ **SPECIAL TOPICS**
- ✓ **Free energy methods**
  Potential of mean force, umbrella sampling, Adaptive bias force method, thermodynamic integration.
- ✓ **Binding and Docking**
  Enzyme-substrate recognition process, Search Algorithms (simulated annealing, steepest descent, genetic algorithms), Scoring Functtions of Docking, Softwares for docking.

Course Outcome

Students will know and have experience in simulations of multiple types: molecular dynamics, Monte Carlo, reaction diffusion, stochastic.

References:

1. Understanding Molecular Simulation: From Algorithms to Applications by Berend Smit and Daan Frenkel
2. Molecular Modeling and Simulation by Tamar Schlick

8) 10-LIFE24-603-E: Population Biology, Ecology And Evolution (30 Lecture Hrs)

Coordinators: Sitabhra Sinha (sitabhra@imsc.res.in)

Course Details:

✓ **Single species population**

- Continuous and discrete-time models of population growth (Logistic and related models)
- Models of age-structured populations
- Population dynamics in the presence of noise
- Time-series analysis of data
- Flies: Model experimental organism for studying population dynamics
- Modeling migration of populations
- Territorial behavior
- Fundamentals of game theory
- Evolution of cooperation between individuals
- Spatial dynamics of strategies (Example: Spatial Prisoner's Dilemma)

✓ **Interaction between multiple populations**

- Introduction to food webs and ecological interactions between species
- Predator-prey interactions: Lotka-Volterra and related models
- Functional response
- Competition
- Cooperation
- Multiple prey and predators: Generalized Lotka-Volterra and related models
- Stability vs complexity in ecosystems: Single trophic level
- Stability vs complexity in ecosystems: Multiple trophic levels
- Experimental techniques for studying impact of diversity on stability
- The robustness of complex ecological networks

✓ **Evolution and population genetics**

- Importance of waves in biology for communication and coordination
- Fundamentals of population genetics: Random mating and Hardy-Weinberg principle
- Classical mathematical genetics: Single locus with multiple alleles
- Classical mathematical genetics: Multiple loci
- X-linked genes; Linkage and its distribution
- The molecular basis of classical genetics
- Fitness landscapes and mathematical models of evolution
- The major transitions in evolution
- Mutation and natural selection
- Random genetic drift
- Neutral theory of evolution
- Coevolution and evolutionary game theory
- Evolutionary ecology

Course Outcome:

Students will know various models of population growth and dynamics, behavioural models and game theory, population interactions, predator-prey models and generalizations, evolution and population genetics, mathematical ecology.

References:

1. Complex Population Dynamics: A Theoretical/Empirical Synthesis, by Peter Turchin
2. An Illustrated Guide to Theoretical Ecology, by Ted J. Case
3. Evolution, by Mark Ridley
4. Theoretical Ecology: Principles and Applications, by Robert May and Angela R. McLean
5. The Balance of Nature? Ecological Issues in the Conservation of Species and Communities, by Stuart L. Pimm
6. Evolutionary Games and Population Dynamics, by Josef Hofbauer and Karl Sigmund
7. Evolutionary Dynamics, by Martin A. Nowak

10-LIFE24-604-E: Computational Neuroscience (30 Lecture Hrs)

Coordinators: Sitabhra Sinha
(sitabhra@imsc.res.in)

Course Details:

✓ **Neurons, Synapses, Gap Junctions and Small Circuits**
- Introduction to the biological components of the nervous system
- Types of Neurons and Glial cells
- Neuronal activity: Action potential and Graded potential
- Ion channels and electrical activity of neurons
- Dynamics of graded potential neurons (Example: retina)
- Dynamics of action potential neurons, spikes and spike trains
- Dynamics of inter-neuron communication: Synaptic transmission
- Dynamics of inter-neuron communication: Gap junctions
- Introduction to GENESIS/NEURON simulation platforms
- Neuron-Glial interaction
- Small neuronal circuits and motifs

✓ **Systems Neuroscience**
- Introduction to the computational perspective for studying the brain
- Introduction to Neural Network Models: McCulloch-Pitts paradigm
- Associative Memory and the Hopfield Network
- Storage capacity and stability of memories in Hopfield Network: Mean-field theory
- Learning: Donald Hebb's Hypothesis, Long-Term Potentiation and STDP
- Perceptron and related models: learning to generalize
- Dynamics of Learning: Hebbian and Competitive principles
- Information theory and neuro-communication
- Development of the nervous system in a growing organism
- Evolution of the nervous system: from single cells to the brain
- Invertebrate neuroscience: C. elegans as a model organism
- Modeling the nervous system of invertebrates
- Sensory-motor integration in the nervous system

✓ **Vision and cognitive neuroscience**
- Introduction to Sensory Processing in the Nervous System
- Components of the Visual System
- Dynamics of Early Visual Processing at Retina
- Receptive fields and centre-surround principle (Mach bands, etc.)
- Processing at the Primary Visual Cortex and Higher Brain Areas
- Modeling edge detection, shape from texture and motion detection
- Visual binding: Synchronization of neuronal activity
- Optical illusions as tool for studying vision
- Information theory of vision
- Introduction to cognitive neuroscience
- Experimental tools of cognitive neuroscience: fMRI, PET, etc.
- Linguistic ability: A model system for cognitive neuroscience

Course Outcome:

Students will know the basics of neuroscience: neurons, glia, their structure and connectivity, dynamics, and various applications to and insights from computational systems and neural networks.

References:

1. From Neuron to Brain: A Cellular Approach to the Function of the Nervous System,by Stephen W. Kuffler, John G. Nicholls and A. Robert Martin
2. Dynamical Systems in Neuroscience: The Geometry of Excitability and Bursting, by Eugene M. Izhikevich
3. Theoretical neuroscience, by Laurence F. Abbott and Peter Dayan
4. Principles of Computational Modelling in Neuroscience, by David Sterratt, Bruce Graham, Andrew Gillies and David Willshaw
5. Seeing: The Computational Approach to Biological Vision, by John P. Frisby and James V. Stone
6. Networks of the Brain, by Olaf Sporns
7. Rhythms of the Brain, by Gyorgy Buzsaki

10-LIFE24-605-E: Modeling Of Infectious Diseases (30 Lecture Hrs)

Coordinators: Sitabhra Sinha (sitabhra@imsc.res.in)

Course Details:

✓ **Genomics & evolutionary biology of pathogens**
- Dynamics of molecular evolution
- Vertical and horizontal gene transfer
- Genomic landscape of pathogens, vectors and humans (Example: malaria); Coevolution and Red queen hypothesis
- Gene regulation, pathogenesis and immune response
- Evolution of virulence

✓ **The biology and modeling of host-pathogen interactions**
- The immune system: design, phylogeny and ontogeny
- The functional anatomy of immune response
- Analysis of idiotypic network interactions
- Systems biology principles for intra-cellular signaling in immune response
- Systems-level modeling of Mycobacterium tuberculosis host-parasite protein-protein interactions
- Micro-epidemiology: population dynamics of viruses and host cells, May-Nowak and related models; application to HIV

✓ **Epidemiology: data analysis and mathematical modeling**
- Epidemics: Dynamics and basic reproductive ratio R0
- Estimation of R0 from data - statistical techniques
- Immunization and other public health intervention strategies
- SIR model of epidemics: derivation and solution
- Variants of SIR model: SEIR, SIS and SIRS
- Modeling vector-borne diseases
- Host-parasite models (example: Nicholson-Bailey model)
- Cellular automata models
- Eco-epidemiological models
- Contact network: structure and dynamics
- Agent-based models of infection propagation

Course Outcome:
Students will know basics of genomics and evolution of pathogens, pathogenesis and immune response, host-pathogen interactions, epidemiology and epidemiological models.

Reference:

1. Modeling Infectious Diseases in Humans and Animals, by Matt J. Keeling and Pejman Rohani
2. Virus Dynamics: Mathematical Principles of Immunology and Virology, by Martin Nowak and Robert May
3. Plagues and Peoples, William H. McNeill
4. Infectious Diseases of Humans: Dynamics and Control, by Roy M. Anderson and Robert May
5. Epidemics: Models and Data using R, Ottar N. Bjørnstad

10-LIFE24-606-E: Next-Generation Sequencing: Technologies, Algorithms, Applications (30 Lecture Hrs)

Coordinators: Areejit Samal (asamal@imsc.res.in)

Course Details:

✓ **Basics**

Next-generation sequencing technologies -- Illumina, SoLiD, Ion Torrent: basics, operations, limitations of each Illumina platform: read quality checking, in detail; Single-end vs paired-end reads.

✓ **Assays, overview**

High-throughput assays based on NGS: RNA-seq, ChIP-seq, ChIP-exo, bisulfite-sequencing; DNA accessibility (DNAse-seq, Faire-seq, Atac-seq); chromatin conformation (Hi-C and related, Chia-pet and similar); and basic algorithms for analysis of above.

✓ **Genome assembly algorithms**

Overlap-layout-consensus algorithms, de Bruijn graph based algorithms, difficulties, contigs and supercontigs, how to "finish" genomes, future perspectives.

✓ **Basic string algorithms**

Substring-matching -- Knuth-Morris-Pratt and Boyer-Moore (for familiarity), suffix trees, suffix arrays, Burrows-Wheeler transform and FM index.

✓ **Read mapping programs**

Using suffix trees (RNA-star), using BWT (hisat2, bowtie, BWA) Transcript assembly and quantification: Basic concepts in assembling, estimating expression/relative expression; tools: Cufflinks, pseudoalignment-based algorithms (Salmon, Kallisto) Graph-based genome alignment: Representing a "pan-genome" as a graph, BWT on a graph, HISAT2

✓ **Peak-calling**

In ChIP-seq, ChIP-exo; motif-finding in ChIP-seq data Analysis of actual RNA-seq datasets (using hisat2, cufflinks), and ChIP-seq datasets (using bwa/macs/gem) Single-cell RNA-seq, atac-seq: techniques and challenges New technologies and assays: Nanopore (long reads); STARR-seq and STAP-seq Original literature discussion, student seminars

Course Outcome:

Students will know the various platforms and technologies available for NGS, the sort of data that they provide, possible assays that involve NGS (RNA-seq, ChIP-seq, Hi-C etc), algorithms to analyse NGS data.

References:

1. Compeau and Pevzner, "Bioinformatics Algorithms"
2. Gusfield, "Algorithms on Strings, Trees, and Sequences"
3. Original literature

10-LIFE24-607-E: Machine Learning (30 Lecture Hrs)

Coordinators: Rahul Siddharthan
(rsidd@imsc.res.in)

Course Details:

While the theory is general, applications will focus on biomedical problems. Basics of probability theory and statistics (univariate and multivariate models); discrete and continuous probability distributions; Bayesian probability theory, priors, conjugate priors and posteriors for discrete distributions; probabilistic models, parameters and hyperparameters.

- ✓ **Basics of machine learning**
  Supervised, unsupervised, reinforcement learning, examples.
- ✓ **Unsupervised ML**
  Clustering (agglomerative clustering, k-means, Gaussian mixture models, t-SNE, etc)
- ✓ **Review of linear algebra**
  Dimensionality reduction: principal component analysis, t-SNE, UMAP
- ✓ **Supervised learning, classification problems**
  Linear models: linear regression, logistic regression, ridge and lasso penalties, generalized linear models.
- ✓ **Model selection**
  AIC, BIC, Bayesian Occam razor; dangers of overfitting; using training/validation/testing sets, bias-variance trade-off.
- ✓ **Other supervised learning methods**
  Naive Bayes, decision trees, random forests and gradient boosting, support vector machines. Introduction to neural networks and deep networks; reinforcement learning, generative adversarial networks.
- ✓ **Other topics**
  Feature selection, missing data information.
  Applications to biology and medicine: transcriptomics and clustering, sequence analysis and regulatory site prediction, protein structure prediction, image analysis and biomedical applications; literature; hands-on exercises based on scikit-learn library.

Course Outcome:

Students will know the basics of supervised and unsupervised machine learning, including clustering algorithms, linear models / regression, neural networks, etc, and applications to problems in biomedicine.

References:

1. Tom Mitchell, "Machine Learning: An Artificial Intelligence Approach" (1997)
2. James, Witten, Hastie, Tibshirani, "An introduction to statistical learning" (2nd ed, 2021)
3. Kevin Murphy, "Probabilistic Machine Learning: An Introduction" (2022)
4. SciKit-Learn library documentation (online)
5. Literature applications