Degree Completion Requirements for AY2020/2021

The OIST Graduate School offers an integrated doctoral program leading to the degree of Doctor of Philosophy (PhD). The degree of PhD is a research postgraduate degree. Such a degree shall be awarded to a candidate who

1. meets admission requirements and receives and accepts an offer of admission, and is registered as a full-time PhD student for a minimum of three years and not more than ten years; and
2. satisfactorily completes prescribed work amounting to at least 30 credits (20 from electives, 10 from mandatory courses) or alternatively, has obtained the equivalent number of credits based on prior study; and
3. presents a successful thesis representing the result of the candidates research which should constitute an original contribution to knowledge and contain material worthy of publication; and
4. satisfies the examiners in an oral examination in matters relevant to the subject of the thesis.

Note 1: coursework credits based on prior study can be waived up to a maximum of 10 elective credits to recognise relevant prior learning, at the advice of the mentor and with approval of the Graduate School. This is not a guarantee that such waiver will be made, in full or part. The amount of waiver due to prior relevant coursework is at the discretion of the mentor.

Note 2: a published paper or manuscript ready for publication from the research work presented in the thesis shall be submitted with the thesis to denote that the "material is worthy of publication". Students in AY2016 cohort and onwards must provide evidence that a paper has been submitted, if none has been published.

Note 3: after successful examination of the written thesis, a thesis defence is conducted before two external examiners on-site in an oral exam. A public presentation of the thesis is required, and takes place immediately preceding the closed examination.

Note 4: examination and final versions of the thesis are submitted only as PDF files. All theses are published online in the OIST Institutional Repository. Partial embargo periods are available by negotiation.

Note 5: from AY2020, theses may be presented as a monolithic dissertation or, newly, as a thesis by publication. See Academic policies for further details.

Elective Courses Offered in AY2020/2021

September 2020 - August 2021

A101 Adaptive Systems

Course Coordinator:

Kenji Doya

Description:

This course is based on a book KD is writing, "Brain Computation: A Hands-on Guidebook" using Jupyter notebook with Python codes.
The course will be in a "flipped learning" style; each week, students read a draft chapter and experiment with sample codes before the class.
In the first class of the week, they present what they have learned and raise questions.
In the second class of the week, they 1) present a paper in the reference list, 2) solve exercise problem(s), 3) make a new exercise problem and solve it, or 4) propose revisions in the chapter.
Toward the end of the course, students work on individual or group projects by picking any of the methods introduced in the course and apply that to a problem of their interest.

Students are assumed to be familiar with Python, as covered in the Computational Methods course in Term 1, and basic statistics, as covered in the Statistical Tests and Statistical Modeling courses in Term 2.

Aim:

This course aims to provide common mathematical frameworks for adaptation at different scales and to link them with biological reality.

Course Content:

1. Introduction
2. Computing Neurons
3. Supervised Learning
4. Reinforcement Learning
5. Unsupervised Learning
6. Bayesian Approaches
7. Deep Learning
8. Multiple Agents
9. Learning to Learn
10. Project Presentation

Course Type:

Elective

Credits:

2

Assessment:

Midterm Reports 60% (2 x 30%), Final Exam 40%.

Text Book:

Rich Sutton & Andy Barto (2018) Reinforcement Learning: An Introduction, 2nd edition. MIT Press (http://incompleteideas.net/book/the-book-2nd.html)

Ian Goodfellow, Yoshua Bengio & Aaron Courville (2016) Deep Learning. MIT Press (http://www.deeplearningbook.org)

Reference Book:

Kenji Doya (in preparation) Brain Computation: A Hands-on Guidebook. (https://github.com/oist/BrainComputation)

Chris Bishop (2006) Pattern Recognition and Machine Learning. Springer

Rich Sutton & Andy Barto (2018) Reinforcement Learning: An Introduction, 2nd edition. MIT Press (http://incompleteideas.net/book/the-book-2nd.html)

Jörgen Weibull (1995) Evolutionary Game Theory. MIT Press.

Python Scientific Lecture Notes (http://www.scipy-lectures.org)

Prior Knowledge:

Assumes good knowledge of statistics and ability to look at biological problems in a mathematical way.

OIST courses to complete beforehand: B31Statistical Tests and/or B32 Statistical Modeling

A102 Mathematical Methods of Natural Sciences

Course Coordinator:

Jonathan Miller

Description:

This course develops advanced mathematical techniques for application in the natural sciences. Particular emphasis will be placed on analytical and numerical, exact and approximate methods, for calculation of physical quantities. Examples and applications will be drawn from a variety of fields. The course will stress calculational approaches rather than rigorous proofs. There will be a heavy emphasis on analytic calculation skills, which will be developed via problem sets.

Aim:

To develop expertise in application of advanced mathematical methods for natural scientists

Course Content:

1. Complex Analysis I: Introduction to complex analysis: analytic functions.
2. Complex Analysis II: Cauchy Theorem and contour integration.
3. Complex Analysis III: Numerical methods in complex analysis.
4. Linear algebra I: Advanced eigenvalues and eigenvectors.
5. Linear algebra II: Numerical methods.
6. Ordinary differential/difference equations (ODDE) I: Properties and exact solutions.
7. ODDE II: Approximate solutions.
8. ODDE III: Numerical solution.
9. Asymptotic expansion of sums and integrals I: elementary methods.
10. Asymptotic expansion of sums and integrals II: steepest descents.
11. Perturbation methods.
12. Boundary layer theory.
13. WKB theory.

14. Vector fields, Stokes' theorem.
15. Green's functions.

Course Type:

Elective

Credits:

2

Assessment:

Homework 60%, Midterm Exam 20%, Final Exam 20%

Text Book:

Advanced Mathematical Methods for Scientists and Engineers, Bender and Orszag (1999) Springer

A Guided Tour of Mathematical Physics, Snieder. At: http://samizdat.mines.edu/snieder/

Mathematics for Physics: A Guided Tour for Graduate Students, Stone and Goldbart (2009) Cambridge.

Mathematical methods for Natural Scientists v. 1

Mathematical methods for Natural Scientists v. 2

Reference Book:

Basic Training in Mathematics. R. Shankar. Plenum, 1995.

Geometrical Methods of Mathematical Physics. B. Schutz. Cambridge, 1999.

Statistical Field Theory. G. Mussardo. Oxford, 2009.

Statistical Mechanics: Entropy, Order Parameters and Complexity J.P. Sethna. Oxford, 2008

Prior Knowledge:

Calculus, e.g. A104 Vector and Tensor Calculus

A103 Stochastic Processes with Applications

Course Coordinator:

Simone Pigolotti

Description:

This course presents a broad introduction to stochastic processes. The main focus is on their application to a variety of modeling situations and on numerical simulations, rather than on the mathematical formalism. After a brief resume of the main concepts in probability theory, we introduce stochastic processes and the concept of stochastic trajectory. We then broadly classify stochastic processes (discrete/continuous time and space, Markov property, forward and backward dynamics). The rest of the course is devoted to the most common stochastic processes: Markov chains, Master Equations, Langevin/Fokker-Planck equations. For each process, we present applications in physics, biology, and neuroscience, and discuss algorithms to simulate them on a computer. The course includes “hands-on” sessions in which the students will write their own Python code (based on a template) to simulate stochastic processes, aided by the instructor. These numerical simulations are finalized as homework and constitute the main evaluation of the course.

Aim:

The course is aimed at students interested in modeling systems characterized by stochastic dynamics in different branches of science. Goals of the course are: to understand the most common stochastic processes (Markov chains, Master equations, Langevin equations); to learn important applications of stochastic processes in physics, biology and neuroscience; to acquire knowledge of simple analytical techniques to understand stochastic processes, and to be able to simulate discrete and continuous stochastic processes on a computer.

Course Content:

1) Basic concepts of probability theory. Discrete and continuous distributions, main properties. Moments and generating functions. Random number generators.

2) Definition of a stochastic process and classification of stochastic processes. Markov chains. Concept of ergodicity. Branching processes and Wright-Fisher model in population genetics.

3) Master equations, main properties and techniques of solution. Gillespie algorithm. Stochastic chemical kinetics.

4) Fokker-Planck equations and Langevin equations. Main methods of solution. Simulation of Langevin equations. Colloidal particles in physics.

5) First passage-time problems. Concept of absorbing state and main methods of solution. First passage times in integrate-and-fire neurons.

6) Element of stochastic thermodynamics. Work, heat, and entropy production of a stochastic trajectory. Fluctuation relations, Crooks and Jarzynski relations.

Course Type:

Elective

Credits:

2

Assessment:

Reports (numerical simulations): 60% hands-on sessions, 20% homework assignments, 20% participation in class

Text Book:

“Random walks in Biology” by H. C. Berg (1993) Princeton University Press

“Stochastic Methods: A Handbook for the Natural and Social Sciences” by C. Gardiner (2009) Springer

Reference Book:

“An Introduction to Probability Theory and its Applications, Vol 1” by W. Feller (1968) Wiley

“The Fokker-Planck Equation”, by H. Risken (1984) Springer

Prior Knowledge:

- Basic calculus: students should be able to calculate integrals, know what a Fourier transform is, and solve simple differential equations.

- Basic probability theory: students should be familiar with basic probability theory, e.g. discrete and continuous distributions, random variables, conditional probabilities, mean and variance, correlations. These concepts are briefly revised at the beginning of the course.

- Scientific programming: the students are expected to be already able to write, for example, a program to integrate a differential equation numerically via the Euler scheme and plot the results. Python is the standard language for the course. The students are required to install the Jupiter notebook system and bring their own laptop for the hands-on sessions.

A104 Vector and Tensor Calculus

Course Coordinator:

Eliot Fried

Description:

A geometrically oriented introduction to the calculus of vector and tensor fields on three-dimensional Euclidean point space, with applications to the kinematics of point masses, rigid bodies, and deformable bodies. Aside from conventional approaches based on working with Cartesian and curvilinear components, coordinate-free treatments of differentiation and integration will be presented. Connections with the classical differential geometry of curves and surfaces in three-dimensional Euclidean point space will also be established and discussed.

Course Content:

1. Euclidean point and vector spaces
2. Geometry and algebra of vectors and tensors
3. Cartesian and curvilinear bases
4. Vector and tensor fields
5. Differentiation and integration
6. Covariant, contravariant, and physical components
7. Basis-free descriptions
8. Kinematics of point masses
9. Kinematics of rigid bodies
10. Kinematics of deformable bodies

Course Type:

Elective

Credits:

2

Assessment:

weekly problem sets, a midterm examination, and a final examination

Text Book:

none, working from personal notes

Reference Book: none

Prior Knowledge: multivariate calculus and linear (or, alternatively, matrix) algebra

A105 Nonlinear Waves: Theory and Simulations

Course Coordinator:

Emile Touber

Description:

Many physical processes exhibit some form of nonlinear wave phenomena. However diverse they are (e.g. from engineering to finance), however small they are (e.g. from atomic to cosmic scales), they all emerge from hyperbolic partial differential equations (PDEs). This course explores aspects of hyperbolic PDEs leading to the formation of shocks and solitary waves, with a strong emphasis on systems of balance laws (e.g. mass, momentum, energy) owing to their prevailing nature in Nature. In addition to presenting key theoretical concepts, the course is designed to offer computational strategies to explore the rich and fascinating world of nonlinear wave phenomena.

By the end of this course, participants dealing with wave-like phenomena in their research field of interest should be able to identify components that can trigger front-like structures (e.g. shocks, solitons) and be able to explore their motion numerically. Whilst the course is aimed at graduate students with an engineering/physics background, biologists interested in wave phenomena in biological systems (e.g. neurones, arteries, cells) are also welcome. However, it is assumed that participants have prior knowledge of maths for engineers and physicists.

Aim:

The target student has completed an engineering, physics or applied maths degree and is embarking on a PhD topic which involves in one way or another some nonlinear wave phenomena. The potential audience is therefore broad in terms of its interest but is expected to know the basic maths and physics from the aforementioned degrees. Although the course includes a large theoretical component it is designed to build a core knowledge of computational approaches to solve nonlinear waves. It is therefore not suited to students only interested in mathematical approaches, and could for example appeal more to the bio-physicist or quantum physicist looking into building a numerical model of wave-like phenomena in biology or physics.

Course Content:

Each week will be split into a theoretical and numerical component, as follows:

Theory (2 hours per week)
01 Hyperbolic PDEs, characteristics
02 Shockwaves: genesis, weak solutions, jump conditions
03 Burgers' equation
04 Shock-boundary/-perturbation/-shock interactions
05 Waves in networks
06 Systems of balance laws
07 Shocks in systems of hyperbolic PDEs
08 Admissibility and stability of shocks

09 Shock tubes
10 Shock-refraction properties
11 Extension to multiple dimensions
12 Dispersive waves
13 Dissipative solitons

Simulations (2 hours per week)
01 Computer arithmetic, numerical chaos
02 Time marching schemes, error types and their measurements
03 Linear advection-diffusion equations, linear stability
04 Burgers’ equation, non-linear stability, TVD and shock-capturing schemes
05 Specifying and implementing well-posed boundary conditions
06 Simulating traffic waves at a junction
07 N-body simulations to measure macroscopic thermodynamic variables
08 Solving the 1D Euler equation, notions of high-performance computing
09 Solving the Riemann problem
10 Solving shock-refraction problems
11 Solving the 2D Euler equations, breakdown to turbulence
12 Simulating a tidal bore
13 Simulating biological patterns emerging from the Gray-Scott equations

In-class notes are based on a number of excellent books, including but not limited to:

On waves
“Linear and nonlinear waves” by Whitham
“Nonlinear wave dynamics: complexity and simplicity” by Engelbrecht
“Waves in fluids” by Lighthill

On compressible flows
“Compressible-fluid dynamics” by Thompson
“Nonlinear waves in real fluids” by Kluwick

On continuum mechanics, systems of balance laws
“Non-equilibrium thermodynamics” by Groot
“Rational extended thermodynamics beyond the monatomic gas” by Ruggeri & Sugiyama
“Hyperbolic conservation laws in continuum physics” by Dafermos
“Systems of conservation laws” (2 volumes) by Serre

On solitary waves
“Solitons: an introduction” by Drazin
“Dissipative solitons in reaction diffusion systems” by Liehr

On computational methods
“A first course in computational fluid dynamics” by Aref & Balachandar
“Computational Gasdynamics” by Laney
“Shock-capturing methods for free-surface shallow flows” by Toro
“A shock-fitting primer” by Salas

Course Type:

Elective

Credits:

2

Assessment:

Individual project: first report: 25%, final report: 50%, final presentation: 25%

Text Book:

In-class notes

Prior Knowledge:

Prior knowledge of maths for engineers and physicists.

A106 Computational Mechanics

Course Coordinator:

Marco Edoardo Rosti

Description:

Students who complete this course will be able to:

- understand the most common techniques for the numerical solution of partial differential problems (such as finite differences and finite volumes),
- evaluate and comment on the stability and convergence of the numerical methods,
- and solve numerically diffusion, convection and transport problems in multiple dimensions.

Target Students: Students interested in solving partial differential equations numerically and in understating possibilities and limitations of numerical techniques. Students should have a general knowledge of partial differential equations.

Aim:

This course aims to provide the mathematical and numerical tools to solve problems governed by partial differential equations. These techniques have wide application in many areas of physics, engineering, mechanics, and applied mathematics.

Course Content:

Revision of numerical differentiation and integration.
Classification of PDE - elliptic, parabolic and hyperbolic equations.
Introduction to Python/MATLAB.
Elliptic equations.
Finite difference method, convergence and stability.
Parabolic equations.
Iterative methods.
Finite volume method.
Analogy with finite differences.
Hyperbolic equations.
Method of characteristics.
System of partial differential equations.
Navier-Stokes equations
Note on multiphase flows.
Final overview and questions

Course Type:

Elective

Credits:

2

Assessment:

Weekly exercise solutions (60%), Final exam (40%)

Reference Book:

Smith, Numerical solution of partial differential equations: Finite Difference methods

Ferziger and Peric, Computational Methods for Fluid Dynamics

Quarteroni, Numerical Models for Differential Problems

Prior Knowledge:

Students should have a general knowledge of partial differential equations. such as from the course B28.
A basic knowledge of Python, MATLAB or any other programming language is preferred but not essential.

A107 Lie Algebras

Course Coordinator:

Liron Speyer

Description:

Students will learn the basic structure theory of simple Lie algebras over the complex numbers, as well as the theory of their highest weight representations. This will develop students' understanding of these fundamental objects in algebra, and give them some hands-on experience computing representations and proving some powerful (and quite beautiful!) results.

Students will learn the basic structures of simple Lie algebras over the complex numbers, including classification, root systems, Cartan subalgebras, Cartan/triangular decomposition, Dynkin diagrams, Weyl groups, and the Killing form. We will develop a highest weight theory of representations, including Verma modules and enveloping algebras. We will end with Weyl's character formula for finite-dimensional simple modules.

Aim:

Students wanting to learn graduate-level algebra, and especially representation theory. A solid grasp of linear algebra will be assumed, as well as an ability to understand and construct quite sophisticated mathematical proofs.

Course Content:

1) Definition and key examples of Lie algebras
2) Structure theory of Lie algebras
3) Root systems, Dynkin diagrams, and Weyl groups
4) Classification of finite-dimensional (semi-)simple Lie algebras

5) Highest weight modules, simple modules, and Verma modules
6) Weyl's character formula for finite-dimensional simple modules

Course Type:

Elective (alternating years)

Credits:

2

Assessment:

Homework: 100%. There will be roughly 5 sets of homework problems during the term.

Text Book:

Introduction to Lie Algebras and Representation Theory, by James Humphreys

Reference Book:

Representation Theory: A first course, by William Fulton and Joe Harris

Introduction to Lie Algebras, by Karin Erdmann and Mark Wildon

Prior Knowledge:

A solid grasp of undergraduate linear algebra, as well as experience following long proofs and constructing your own proofs. Students must be very comfortable with proofs in order to understand the material in this course and complete the homework questions adequately. If you are unsure, please discuss this further with your academic mentor. Some prior knowledge of the representation theory of finite groups will also be helpful when grappling with analogous results for Lie algebras, but it is not completely necessary.

A203 Advanced Optics

Course Coordinator:

Síle Nic Chormaic

Description:

Review of geometrical optics; wave properties of light and the wave equation; Helmholtz equation; wave optics, including Fresnel and Fraunhofer diffraction, transfer functions, coherence, auto and cross-correlation; Gaussian and non-Gaussian beam profiles; quantum optics and photon statistics; spin squeezing; applications of optics including fiber optics, laser resonators, laser amplifiers, non-linear optics, and optical trapping; quantum properties of light; interaction of photons and atoms.

Aim:

To introduce students to fundamental and advanced topics in modern optics and photon physics.

Course Content:

1. Review of classical optics
2. Ray and wave optics
3. Laser optics and Gaussian beams
4. Non-Gaussian beam optics

5. Fourier optics
6. Electromagnetic optics
7. Nonlinear optics
8. Lasers, resonators and cavities
9. Photon optics
10. Photon statistics and squeezed light
11. Interaction of photons with atoms
12. Experimental applications: Optical trapping
13. Experimental applications: Laser resonator design
14. Experimental applications: Light propagation in optical fibers and nanofibers
15. Experimental applications: laser cooling of alkali atoms
16. Laboratory Exercises: Mach-Zehnder & Fabry-Perot Interferometry; Fraunhofer & Fresnel Diffraction; Single-mode and Multimode Fiber Optics; Polarization of Light; Optical Trapping & Optical Tweezers

Course Type:

Elective (Alternating years)

Credits:

2

Assessment:

Continuous Assessment: 60%, Final Exam, 40%.

Text Book:

Fundamentals of Photonics, by Saleh and Teich (2007) Wiley

Reference Book:

Quantum Optics, an Introduction, by Mark Fox (2006) Oxford University Press

Optics, by Eugen Hecht (2001) Addison Wesley

A205 Quantum Field Theory

Course Coordinator:

Shinobu Hikami

Description:

This course covers quantum field theory. Due to recent developments, we organize it with emphasizing statistical field theory.

The renormalization group method, symmetry breaking, gauge field and string theory, random matrix theory are key ingredients.

Aim:

To introduce students to basic concepts and techniques in relativistic quantum field theory.

Course Content:

1. An electron in a uniform electromagnetic field: Landau levels
2. Canonical Quantization
3. Antiparticles
4. Particle decay
5. Feynman rules and the S-matrix
6. Weyl and Dirac spinors
7. Gauge Theories
8. Quantization of the electromagnetic field
9. Symmetry breaking
10. Path integrals
11. Aharonov-Bohm effect
12. Renormalization
13. Quantum chromodynamics
14. Nuclear forces and Gravity
15. Field unification

Course Type:

Elective

Credits:

2

Assessment:

Homework: 60%, Final Exam, 40%

Text Book:

E. Brezin, Introduction to Statistical Field Theory (Cambridge University Press)

Reference Book:

Quantum Field Theory, by Michio Kaku (1993) Oxford University Press.

An Introduction to Quantum Field Theory, by Peskin and Schroder (1995) Westview Press.

Gauge Theories in Particle Physics, Vol. I and II, by Aitchison and Hey (2004) Institute of Physics

Prior Knowledge:

Firm grounding in Quantum Mechanics

B11 Classical Electrodynamics

A208 Bioorganic Chemistry

Course Coordinator:

Fujie Tanaka

Description:

This course covers essential concepts and recent advances in the design and synthesis of functional molecules used for understanding and controlling biological systems. Topics of this course include design and synthesis of small organic molecules, organic reactions, methods for controlling reaction pathways, asymmetric synthesis, mechanisms of catalysis and molecular recognition, and creation of designer proteins and peptides.

Aim:

To discuss design and synthesis of functional molecules used for understanding and controlling biological systems.

Course Content:

1. Methods of chemical transformations to access designer molecules
2. Strategies for the development of new reaction methods including stereoselective reaction methods
3. Asymmetric reactions and asymmetric catalysis
4. Catalytic enantioselective reactions: Carbon-carbon bond forming reactions
5. Catalytic enantioselective reactions: hydrolysis, reduction, dynamic kinetic resolutions, etc.
6. Organocatalysis
7. Design and synthesis of functional molecules
8. Chemical mechanisms of bioactive molecules including chemistry of enzyme inhibitors
9. Molecular recognition and non-covalent bond interactions
10. Enzyme catalysis and catalytic mechanisms
11. Enzyme catalysis and small organic molecule catalysis
12. Enzyme kinetics and kinetics of non-enzymatic reactions
13. Strategies for the development of new designer catalysts
14. Methods in identification and characterization of organic molecules
15. Chemical reactions for protein labeling; chemical reactions in the presence of biomolecules

Course Type:

Elective

Credits:

2

Assessment:

Exercises 50%, reports 50%

Text Book:

Strategic Applications of Named Reactions in Organic Synthesis, Kurti and Czako (2005)

Reference Book:

Advanced Organic Chemistry, Part B: Reactions and Synthesis, Carey and Sundberg (2007)

Advanced Organic Chemistry, Part A Structures and Mechanisms, Carey and Sundberg (2007)

Organic Chemistry, McMurry

A209 Ultrafast Spectroscopy

Course Coordinator:

Keshav Dani

Description:

This course will be an introductory graduate level course to initiate students into the techniques of ultrafast spectroscopy. They will be introduced to the basic concepts underlying sub-picosecond phenomena in nature (ultrafast chemical processes, femtosecond electron dynamics in materials, etc.) and the tools used to study such phenomena (pump-probe spectroscopy, Terahertz Time Domain Spectroscopy, etc.).

Aim:

This course provides an overview of the modern methods and applications in ultrafast spectroscopy.

Course Content:

1. Introduction, History and Development:
2. Basic Concepts
3. Understanding Ultrafast Pulses: Spectrum, Fourier Transform, Uncertainty Principle, wavelength, repetition rate
4. Understanding Ultrafast Pulses & Capabilities: Time Resolution, Nonlinearities,
5. Ultrafast pulse measurement: Spectrum, Phase, Amplitude, Intensity
6. Ultrafast pulse measurement: AutoCorrelation, FROG, SPIDER
7. Ultrafast Techniques: Pump Probe, Four-Wave Mixing, or others.
8. Ultrafast Techniques: Time Resolved Fluorescence, Up-converstion, or others.
9. Ultrafast Techniques: THz-TDS, Higher Harmonic Generation, or others.
10. Ultrafast Techniques: Single Shot Measurements, etc.
11. Applications: e.g. Condensed Matter Physics
12. Applications: e.g. Chemistry and Materials Science
13. Applications: e.g. Biology

Course Type:

Elective

Credits:

2

Assessment:

Homework and Exercises, 80%; End of Class Presentation, 20%

Text Book:

No text set, students will work from primary sources that will be advised

A210 Advanced Quantum Mechanics

Course Coordinator:

Thomas Busch

Description:

Advanced course in Quantum Mechanics, based on recent theoretical and experimental advances. Evolution in Hilbert space and quantum bits; conditional quantum dynamics; quantum simulations; quantum Fourier transform and quantum search algorithms; ion-trap and NMR experiments; quantum noise and master equations; Hilbert space distances; Von Neumann entropy; Holevo bound; entanglement as a physical resource; quantum cryptography; lab: quantum eraser, interaction free measurement.

Aim:

To introduce students to advanced and recent concepts and techniques in quantum mechanics

Course Content:

1. Quantum Mechanics: Mathematical Framework
2. Quantum Mechanical Postulates
3. Quantum Measurements
4. Quantum Algorithms
5. Quantum Computing: Physical Realisations
6. Quantum Noise
7. Entropy and Information
8. Quantum Statistical Mechanics
9. Quantum Information Theory

Course Type:

Elective (Alternating Years)

Credits:

2

Assessment:

Homework: 20%, Midterm Exams: 2 x 20%, Journal Club: 30%, Lab: 10%

Text Book:

Quantum Computation and Quantum Information, by M.A. Nielsen and I.L. Chuang (2010). Cambridge University Press

Reference Book:

Quantum Information and Coherence, by E. Andersson and P. Ohberg (2014) Springer

Modern Quantum Mechanics, by J.J. Sakurai and J.J. Napolitano (2010) Addison-Wesley

Quantum Information Theory, by M.M. Wilde (2013) Cambridge University Press

Prior Knowledge:

Solid undergraduate Quantum Mechanics preparation.

Students may wish to take this with A273 Ultracold Quantum Gasses and A218 Condensed Matter Physics.

A211 Advances in Atomic Physics for Quantum Technologies

Course Coordinator:

Síle Nic Chormaic

Description:

Advanced level course in atomic physics. Progress in laser control of atoms has led to the creation of Bose-Einstein condensates, ultrafast time and frequency standards and the ability to develop quantum technologies. In this course we will cover the essentials of atomic physics including resonance phenomena, atoms in electric and magnetic fields, and light-matter interactions. This leads to topics relevant in current research such as laser cooling and trapping.

Aim:

To introduce students to recent advances in atomic physics for quantum technologies

Course Content:

1. Early atomic physics
2. The hydrogen atom and atomic transitions
3. Helium and the alkali atoms
4. LS coupling
5. Hyperfine structure
6. Atom interactions with radiation

7. Laser spectroscopy
8. Laser cooling and trapping
9. Bose-Einstein condensation
10. Fermionic quantum Gases
11. Atom interferometry
12. Ion traps
13. Practical elements: Laser spectroscopy
14. Practical elements: Laser cooling of Rb
15. Applications: Quantum computing
16. Practical Exercises : presentations, laboratory exercises on light-matter interactions

Course Type:

Elective (Alternating Years Course)

Credits:

2

Assessment:

Continuous Assessment: 40%, Midterm Exams: 2 x 15%, Final Exam, 30%.

Text Book:

No single textbook will be used during this course.

Reference Book:

Advances in Atomic Physics: An Overview by Cl. Cohen-Tannoudji and D. Guéry-Odelin (2011) World Scientific

Atomic Physics by C.J. Foot (2013) Oxford

Introductory Quantum Optics by C.C. Gerry and P. L. Knight (2005) Cambridge

A212 Microfluidics

Course Coordinator:

Amy Shen

Description:

The interface between engineering and miniaturization is among the most intriguing and active areas of inquiry in modern technology. The aim of this course is to illuminate and explore microfluidics as an interdisciplinary research area, with an emphasis on emerging microfluidics disciplines, including molecular assembly to bulk and device level scales, with applications in novel materials synthesis, bio-microtechnology and nanotechnology.

The course will begin by highlighting important fundamental aspects of fluid mechanics, scaling laws and flow transport at small length scales. We will examine the capillary-driven, pressure-driven, and electro-kinetic based microfluidics. We will also cover multi-phase flow, droplet-based microfluidics in microfluidics. This course will also illustrate standard microfabrication techniques, micro-mixing and pumping systems.

Aim:

To introduce students to fundamental fluid transport physics at the micron and nanometer scale for applications in micro/nanofluidic devices. This course will also illuminate and explore microfluidics as an interdisciplinary research area, with an emphasis on emerging microfluidics disciplines.

Course Content:

1. Introduction to microfluidics; Scaling analysis
2. Low Reynolds number flows
3. Pressure-driven microfluidics
4. Capillary-driven microfluidics
5. Microfabrication
6. Diffusion in microfluidics
7. Mixing in microfluidics
8. Droplet microfluidics and 2-phase flows
9. Bio-MEMs

Course Type:

Elective

Credits:

2

Assessment:

Homework: 20%, Midterm Exam: 30%, Lab: 20%, Course Project: 30%

Text Book:

Introduction to Microfluidics by Patrick Tabeling, 2010, Oxford University Press

Reference Book:

Fundamentals and Applications of Microfluidics by Nam-Trung Nguyen and Steve Wereley, Artech House; 2002.

Micro- and Nanoscale Fluid Mechanics: Transport in Microfluidic Devices, by Brian Kirby, Cambridge University Press, 2013.

Prior Knowledge:

A good pass in B13 Fluid Mechanics is required pre-knowledge for A212. If you have taken Fluid Mechanics from your former B.S or M.S Universities, please contact Prof. Amy Shen directly to determine whether you are prepared to take A212.

A213 Inorganic Electrochemistry

Course Coordinator:

Julia Khusnutdinova

Description:

In this course, students will learn basic principles of electrochemistry with a particular focus on redox behavior of transition metals including metalloproteins. Modern research in application of transition metal complexes for renewable energy storage and production will be highlighted and discussed in detail, including metal-catalyzed water oxidation, proton reduction and CO2 reduction processes. The course will provide practical training in voltammetric techniques and spectroelectrochemistry, and analysis and simulation of cyclic voltammetry data.

See course highlights at: https://groups.oist.jp/cccu/post/2016/12/16/course-highlights-inorganic-electrochemistry.

Aim:

This course introduces basic principles of electrochemistry, and discusses modern research in the application of transition metal complexes in electrocatalysis for renewable energy storage and production.

Course Content:

1. Basic aspects of electrochemistry
2. Electrochemical instrumentation
3. Cyclic voltammetry: Reversible, irreversible and quasireversible processes

4. Cyclic voltammetry: Effect of coupled chemical reactions; Digital simulation of cyclic voltammograms
5. Bulk electrolysis and pulsed voltammetric techniques
6. Hydrodynamic techniques: application for studying reaction intermediates and mechanisms.
7. Electrochemical behavior of transition metal complexes.
8. Redox-active metalloproteins
9. Redox-induced structural reorganization of metal complexes
10. Electrocatalysis by transition metals for renewable energy production and storage: water splitting to O_2 and H_2
11. Transition metal-catalyzed electroreduction of CO_2 and dehydrogenation of formic acid and alcohols: application for hydrogen storage
12. Immobilization of metal catalysts on electrode surface
13. Photoelectrochemistry
14. Application of electrochemical processes in chemical industry

Course Type:

Elective

Credits:

2

Assessment:

Laboratory reports: 25%; Homework: 25%; Presentation: 25%; Final exam: 25%

Text Book:

“Inorganic Electrochemistry: Theory, Practice and Application”, Pierro Zanello (2003), RSC.

Reference Book:

Original papers and review articles will be supplied as required.

A214 Nucleic Acid Chemistry and Engineering

Course Coordinator:

Yohei Yokobayashi

Description:

In this course, students will learn basic principles of nucleic acid chemistry and engineering through lectures and discussions. The students will then use the basic knowledge to deepen their understanding of the current research in the field of nucleic acid chemistry and engineering. Emphasis will be placed on reviewing current and future applications of nucleic acids in diverse fields including chemistry, biology, materials, medicine, biosensors, and engineering. Finally, the students will design, construct, and characterize functional nucleic acids in the laboratory while learning basic experimental skills to manipulate nucleic acids.

Aim:

This course introduces the basic principles and current research in nucleic acid chemistry and engineering through lectures, discussions and laboratory sessions.

Course Content:

Basic nucleic acid chemistry (3 hr)

1. Structure (DNA, RNA, unnatural nucleic acids, secondary/tertiary structures)
2. Thermodynamics (hybridization)

Synthesis of nucleic acids (4.5 hr)

1. Chemical synthesis (solid phase synthesis)
2. Biochemical synthesis (PCR, in vitro transcription, gene synthesis, biological synthesis, etc.)

Analysis of nucleic acids (4.5 hr)

1. Chemical analysis (UV, electrophoresis, CD, nuclease probing, SHAPE, etc.)
2. Sequence analysis (Sanger, Illumina, PacBio, nanopore, etc.)

Nucleic Acid Engineering (12-16 hr)

- Synthetic nucleic acids

1. Unnatural bases and backbones
2. Self-assembly, materials
3. Nucleic acid amplification and detection
4. Therapeutics
5. Aptamers
6. Catalytic nucleic acids
7. In vitro selection, in vitro evolution
8. Molecular computation
9. Genome editing

- Biological nucleic acids

1. Riboswitches

2. Ribozymes

Laboratory: Design, construction, and characterization of functional nucleic acids (12-16 hr labs)

Course Type:

Elective

Credits:

2

Assessment:

Reports 50%; Presentations 50%

Text Book:

None

Reference Book:

Original papers will be supplied as required

A216 Quantum Mechanics

Course Coordinator:

Denis Konstantinov

Description:

Basic course in non-relativistic quantum mechanics. Wave functions and the Schrödinger Equation; Hilbert space; central forces and angular momentum; one-dimensional problems including particle in box, tunneling, and harmonic oscillator; hydrogen atom; Pauli principle; scattering; electron spin; Dirac notation; matrix mechanics; the density matrix; time-independent perturbation theory; Heisenberg picture; time-dependent perturbations; degenerate harmonic oscillators; electrons in a uniform magnetic field; quantized radiation field; absorption and emission of radiation; symmetry principles, entanglement.

Aim:

To introduce students to basic concepts and techniques in quantum mechanics

Course Content:

1. Quantum description of a particle, Schrödinger equation, notations
2. The Heisenberg picture and implications
3. Spin ½ particles, magnetic field effects and resonance
4. One-dimensional harmonic oscillators, Hamiltonians
5. Particle in a box; tunneling, coupled oscillators
6. Coherent states; phonons and photons
7. Angular momentum, spherical harmonics
8. Approximation methods
9. Electrons in a uniform field
10. Time-independent perturbation theory
11. Fine and hyperfine structure of the Hydrogen atom
12. Time-dependent perturbation theory
13. Scattering theory
14. Radiation and absorption
15. Entanglement and information transfer

Course Type:

Elective

Credits:

2

Assessment:

Homework: 20%, Midterm Exams: 2 x 30%, Final Exam, 20%.

Text Book:

Quantum Mechanics: Vol I & II, by Cohen-Tannoudji, Diu, Laloe (1977). Wiley-Interscience

Reference Book:

Principles of Quantum Mechanics 2 edn, by Shankar (1994) Springer

Atom-Photon Interactions, by Cohen-Tannoudji, Dupont-Roc, Grynberg (1998) Wiley-Interscience

Statistical Mechanics, 3 edn, by Pathria and Beale (2011) Academic Press

(This shorter version of Quantum Mechanics replaced the 2-term course sequence A216 and A217 from previous years, due to COVD teaching restrictions)

A218 Condensed Matter Physics

Course Coordinator:

Yejun Feng

Description:

Condensed matter physics originates from solid state physics in 1950's and evolves into a subject which focuses on collective behavior, symmetry, and topological states. Over the past century, this sub-field of physics has grown with many various ramifications that any offered perspective would always be partial and biased. Nevertheless, I would like to limit this class to the introduction level, and give a broad description of the field. For a few topics, I will try to demonstrate how to evolve from fundamental concepts to perspectives of advanced topics.

Aim:

This is a class designed for beginner students who would pursue a Ph.D. in fields related to physics, materials science, device engineering, and chemistry. The course focuses on three major concepts of lattice, electrons, and spins, and surveys the topics generated by interactions between them. During the weekly four-hour lecture time, I will try to split the time with half on theory and half on experimental demonstration of those theoretical concepts.

Course Content:

(Separated into two-hour lecture each)

1. Crystals and Symmetry

2. Phonons
3. Inelastic probes
4. Order and disorder
5. Phase transitions and Landau's theory
6. Band structure
7. Fermi surface probes
8. Hatree-Fock
9. Electronic excitations in metals
10. Electrical transport and galvanomagnetic phenomena
11. Quantum Hall and fractional quantum Hall
12. Superconductivity: BCS
13. Superconductivity: Quasi-particle gap
14. Superconductivity: GL
15. Josephson tunnelling
16. Josephson devices
17. Parity sensitive probes.
18. Odd parity superconductivity
19. Magnetic interactions
20. Metal-insulator transition
21. WKB and spin-tunneling
22. Itinerant magnetism
23. Spin excitations, spin waves, and magnons
24. Spin glass, spin ice, and spin liquids
25. Quantum phase transitions
26. Experimental study of dynamical exponent

Course Type:

Elective

Credits:

2

Assessment:

Homework (4-5) 70%, final presentation, 30%.

Text Book:

Ashcroft & Mermin, Solid State Physics (1976).

M. Tinkham, Introduction to Superconductivity (1996).

Reference Book:

Chaikin & Lubensky, Principles of Condensed Matter Physics (1995).

D. Pines, Elementary Excitations in Solids (1963).

L. P. Levy, Magnetism and Superconductivity (1997).

S.K. Ma, Modern Theory of Critical Phenomena (1976).

Prior Knowledge:

Students are suggested to have basic (undergraduate) understanding of quantum mechanics and statistics.

A220 New Enzymes by Directed Evolution

Course Coordinator:

Paola Laurino

Description:

During this course, the student will experience a research project. We are planning to run enzyme evolution experiments generating a random library of enzyme mutants and selecting for improved activity in vivo (bacterial strains). Student will create variants of Kan Kynase enzymes. The enzymes will be selected for higher antibiotic resistance to assess improved variants. After a few rounds of evolution, advantageous mutations will be enriched in the variants pool and identified by sequencing. The enriched mutations will be highlighted in the protein structure and then analysed.

Aim:

This course aims to experience different technologies that are used during protein engineering experiments. These technologies will be explained in detail in theory and in practice with the idea that the student can apply them independently during the course project and in future research.

Course Content:

1. Week 1 Recombinant DNA technology: PCR, cloning, site-specific mutagenesis, random mutagenesis (2hrs)

Lab 1.1 Medium preparation, transformation for overexpression of plasmid (4hrs)

Lab 1.2 Plasmid extraction, quantification (4hrs)

2. Week 2 Introduction on enzymes activity: case study Kan Kinase (1hr)

Lab 2.2 PCR gene, DNA gel, DNA purification (6hrs)

Lab 2.3 library generation by error prone PCR, DNA isolation (6hrs)

3. Week 3 Neutral mutations, deleterious mutations, epistatic mutations (1hr)

Lab 3.1 Digestion insert and vector, purification, set up ligation (8hrs)

Lab 3.2 Medium preparation, EtOH purification and transformation in expressing bacterial strains (BL21DE3). (5hrs)

4. Week 4 Sager sequencing introduction (1hr)

Lab 4.1 Colony PCR, DNA isolation, (5hrs)

Lab 4.2 Sager sequencing preparation, Sager sequencing (8hrs)

5. Week 5 Design of a improved enzyme by directed evolution experiments: kan kinase as case study (1hrs)

Lab 5.1 I Round of selection: Preparation of Kan Plate (different conc), Transformation (6hrs)

Lab 5.2 colony PCR of the surviving colonies and plasmid isolation (5hrs)

6. Week 6 Protein visualisation programs introduction -pymol (2hrs)

Lab 6.1 II Round of selection: Preparation of Kan Plate (different conc), Transformation (6hrs)

Lab 6.2 Colony PCR of the surviving colonies and plasmid isolation (5hrs)

7. Lab 7.1 Sager sequencing of a pool of surviving variants (8hrs)

Lab7.2 Extra time to repeat or catch up with experiments (6hrs)

8. Presentation of a research article where they perform Directed Evolution (2-4hrs depending of number of students)

Course Type:

Elective

Credits:

2

Assessment:

Homework: 25%, Laboratory report 50%, Presentation, 25%.

Text Book:

Structure and Mechanism in protein Science. A guide to Enzyme Catalysis and Protein Folding. Alan Fersht, World Scientific.

Prior Knowledge:

Undergraduate level biochemistry or molecular biology

A219 General Relativity

Course Coordinator:

Yasha Neiman

Description:

We begin by introducing tensors in non-relativistic physics. We then give an overview of Special Relativity, and discuss the special nature of gravity as an “inertial force”. With this motivation, we develop the differential geometry necessary to describe curved spacetime and the geodesic motion of free-falling particles. We then proceed to Einstein’s field equations, which we analyze in the Newtonian limit and in the linearized limit (gravitational waves). Finally, we study two iconic solutions to the field equations: the Schwarzschild black hole and Friedman-Robertson-Walker cosmology. We will use Sean Carroll’s textbook as the main reference, but we will not follow it strictly.

Aim:

An introduction to General Relativity, from geometry to applications.

Course Content:

1. Tensors in 3d: moment of inertia and magnetic field
2. Special Relativity in 3d language
3. Special Relativity in 4d language: Minkowski spacetime
4. Gravity as an inertial force: the equivalence principle
5. Curved spacetime: metric and Christoffel symbols
6. Geodesic motion: Newtonian limit, redshift, deflection of light
7. Curved spacetime: The Riemann tensor and its components

8. The Einstein field equations and their Newtonian limit

9. Linearized limit and gravitational waves

10. The Schwarzschild black hole

11. More on the Schwarzschild metric: precession of planets, black hole thermodynamics

12. Friedmann-Robertson-Walker cosmology

Course Type:

Elective (Alternating years)

Credits:

2

Assessment:

Midterm exam 25% (only if helps the final grade); Final exam 75%

Text Book:

“Spacetime and Geometry – an introduction to General Relativity”, Sean Carroll (2003) Addison Wesley

Reference Book:

Landau & Lifshitz vol. 2 (“Classical Theory of Fields”).

“Relativity, Gravitation and Cosmology: A Basic Introduction”, Ta-Pei Cheng.

“General Relativity”, Robert M. Wald.

Prior Knowledge:

Prerequisites: Maxwell’s equations in differential form. Solving Maxwell’s equations to obtain electromagnetic waves. Linear algebra of vectors and matrices.

A221 Relativistic Mechanics and Classical Field Theory

Course Coordinator:

Yasha Neiman

Description:

We begin with a gentle and thorough introduction to Special Relativity, and take some time to have fun with shapes in Minkowski space. We proceed to an advanced treatment of relativistic particles, electromagnetic fields and weak gravitational fields (to the extent that doesn’t require General Relativity). Antiparticles are introduced early on, and we put an emphasis on actions and phase space structures. We introduce the geometric concept of spinors, and the notion of spin for particles and fields. We discuss the Dirac equation and the resulting picture of the electron. We introduce conformal infinity. Time allowing, we discuss a bit of conformal field theory and some physics in de Sitter space.

Aim:

An introduction to Special Relativity, with a variety of applications.

Course Content:

1. Tensors in 3d: moment of inertia, Maxwell’s equations, stresses etc.
2. Special Relativity in 3d language.
3. Special Relativity in 4d language: Minkowski spacetime.
4. Some fun geometry in Minkowski spacetime: spheres, polyhedra etc.
5. Relativistic particles and antiparticles in electromagnetic and weak gravitational fields.
6. Phase space structure in relativistic mechanics.
7. Maxwell’s equations; plane waves and the electromagnetic field of point charges.
8. Linearized Einstein equations; plane waves and the distant gravitational field of point masses.
9. Relativistic thermodynamics and hydrodynamics.
10. Spinors in 3d and 4d.
11. The little group and spin for massive and massless particles.
12. The Dirac equation and the relativistic electron.
13. The conformal boundary of Minkowski spacetime.
14. (*) Conformal symmetry and the embedding-space formalism.
15. (*) An introduction to de Sitter space through the embedding-space formalism.

Course Type:

Elective (Alternating years)

Credits:

2

Assessment:

Midterm exam 25% (only if helps the final grade); Final exam 75%. Mandatory homework submission.

Text Book:

Landau & Lifshitz vol. 2: “Classical Theory of Fields”.

Warren Siegel “Fields” [https://arxiv.org/abs/hep-th/9912205].

Reference Book:

Thomas M. Helliwell. “Special Relativity”

Roger Penrose & Wolfgang Rindler “Spinors and Spacetime, Vol. 1: Two-spinor Calculus and Relativistic Fields”

Prior Knowledge:

Maxwell’s equations in differential form. Solving Maxwell’s equations to obtain electromagnetic waves. Quantum mechanics.

A223 Quantum Materials Science

Course Coordinator:

Yoshinori Okada

Description:

After overviewing various interesting quantum materials and their unique functionalities, this course will introduce the concept of materials design and its realization in bulk single crystal growth and epitaxial thin film growth. Then, the principles of single particle spectroscopy will be introduced, particularly focusing on photoemission and tunneling spectroscopy. This course is ideal for students interested in both crystal growth and spectroscopy in quantum materials science.

During this course, several lectures by external scientists and engineers from R&D companies will be arranged. Also, “4. Group discussion and presentations based on recent literatures” and “6.

Experiencing quantum materials growth and their characterization” will be arranged according to circumstances and students' preference.

Aim:

This course hopes to provide the student with sufficient knowledge to enjoy quantum materials growth and analysis at the frontiers of quantum materials science.

Course Content:

1. Overview of recent interests in quantum materials
2. Materials design concepts and various growth methods
   2-1. bulk single crystal growth
   2-2. epitaxial thin film growth
3. Single particle spectroscopies
   3-1. electronic states in momentum space
   3-2. electronic states in real space
   3-3. heterogeneous electronic states
4. Group discussion and presentations based on recent literatures
5. Lecture by external speakers
   (Lectures will be invited from R&D companies)
6. Experiencing quantum materials growth and their characterization
   (This will be flexibly arranged depending on attendee’s preference)

Course Type:

Elective

Credits:

2

Assessment:

Presentation 50%, Report 50%

Text Book:

None

Prior Knowledge:

Undergraduate level of condensed matter physics

A224 The Earth System

Course Coordinator:

Satoshi Mitarai

Description:

This course will develop student understanding of key components of the Earth system, as well as past and future variability. Topics to be covered include, but are not limited to, global energy balance, atmospheric circulation, surface winds and ocean circulation, deep-sea thermohaline circulation, Holocene climate, the El Niño Southern Oscillation, projections of future atmospheric CO2 and other greenhouse-gas concentrations, and the effects of climate change on marine environments. Hands-on exercises using predictions of the latest atmosphere-ocean coupled general circulation models will be employed to assess how climate change affects oceanic environments, e.g., based upon IPCC future climate change scenarios and past climate records. This course is open to any student, while it mainly targets marine science students. Basic mathematical knowledge (calculus) will be required. Students are expected to apply the skills they acquire in this class to their own marine biological and/or ecological studies to describe the influence of climate change on ocean environments quantitatively, and also to discuss potential outcomes for marine ecosystems on which their own research is focused.

For the project, students will analyze predictions of CMIP (Coupled Model Inter-comparison Project) models to assess the effects of climate change on marine environments, and write a brief report (a few pages) including some figures.

Aim:

Successful students will understand the mechanics of the changing Earth environment. They will also comprehend past global changes and those anticipated in the future due to anthropogenic carbon releases. Students will acquire skills to utilize cutting-edge atmosphere-ocean data coupled with general circulation models, enabling them to assess potential effects of climate change on ocean-atmosphere systems. Target Students This course is designed for students who intend to work on marine biological and/or marine ecological studies in relation to the changing Earth environment. Students with any background are welcome to take this course. Some mathematical skills will be required to understand ocean-atmosphere dynamics, but will be limited to basic calculus (no prerequisite courses). While this course mainly targets marine science students, it will also be useful for those who study terrestrial ecology or related fields.

Course Content:

First, this course covers key components of the Earth system: global energy balance, the greenhouse effect, blackbody radiation, global distributions of temperature, effects of the Earth’s rotation, geostrophic balance, seasonal variability, Hadley circulation, surface winds and ocean circulation, Ekman layers, western boundary currents, and the thermohaline conveyor belt, etc.

Second, the course addresses global change on short and long time scales: long-term climate records, Holocene climate, the last glacial maximum, the El Niño Southern Oscillation, the Pacific Decadal Oscillation, projections of future atmospheric CO2 concentrations, etc.

Furthermore, atmosphere-ocean coupled general circulation models will be introduced. Effects of climate change, such as projected global warming scenarios, on marine environments will be discussed through exercises based on model predictions.

Course Type:

Elective

Credits:

2

Assessment:

Homework (about 5 times): 50%, Project (see below): 50%.

Text Book:

Lee R. Kump, James F. Kasting, Robert G. Crane. The Earth System, 3rd Edition. Pearson, 2010.

Gerold Siedler, Stephen M. Griffies, John Gould, John A. Church. Ocean Circulation and Climate: A 21st Century Perspective. Elsevier, 2013.

Reference Book:

Philippe Bertrand, Louis Legendre. Earth, Our Living Planet. Springer, 2021.

Prior Knowledge:

B28 Elementary Differential Equations and Boundary Problems and/or A104 Vector and Tensor Calculus

A225 Statistical Mechanics, Critical Phenomena and Renormalization Group

Course Coordinator:

Reiko Toriumi

Description:

The course is designed as an introduction to the methods of statistical mechanics and evolves into critical phenomena and the renormalization group.
The analogy between statistical field theory and quantum field theory may be addressed throughout the course.

Key concept which will be emphasized in this course is universality; we concern systems with a large number of degrees of freedom which may interact with each other in a complicated and possibly highly non-linear manner, according to laws which we may not understand. However, we may be able to make progress in understanding behavior of such problems by identifying a few relevant variables at particular scales. The renormalization group addresses such a mechanism.
Some selected topics are planned to be covered, such as conformal field theory, vector models/matrix models, SLE.

Aim:

Students will obtain understanding of modern concepts and techniques in statistical mechanics/statistical field theory, geared toward the common concepts appearing in quantum field theory, namely critical phenomena and the renormalization group. The course is mainly targeted at students who are interested in theoretical works. The course is planned to develop to some advanced topics in the later half.

Course Content:

We plan to cover the following material from Pathria and Beale:
- Chap 1: The Statistical Basis of Thermodynamics
- Chap 2: Elements of Ensemble Theory
- Chap 3: The Canonical Ensemble
- Chap 4: The Grand Canonical Ensemble
- Chap 5: Formulation of Quantum Statistics
- Chap 6: The Theory of Simple Gases
- Chap 7: Ideal Bose Systems
- Chap 8: Ideal Fermi Systems
- Chap 9: Statistical Mechanics of Interacting Systems: Cluster Expansions Method

From Cardy,
Chapter 3: The renormalization group idea
Chapter 5: The perturbative renormalization group
Chapter 11: Conformal symmetry

We may cover some more selected topics such as conformal field theory, vector models/matrix models, SLE, if the time allows.

Course Type:

Elective

Credits:

2

Assessment:

Weekly assignments (40%); midterm exam (30%); final exam or project (30%)

Text Book:

Pathria and Beale, Statistical Mechanics, 2011 Elsevier

John Cardy, Scaling and Renormalization in Statistical Physics

Reference Book:

John Cardy, Conformal Field Theory and Statistical Mechanics

David Tong, online lectures on Statistical Field Theory

John Cardy, Conformal Invariance and Statistical Mechanics (lecture notes)

Prior Knowledge:

Students should have knowledge of Classical Mechanics and Quantum Mechanics to advanced undergraduate level.

A226 Synthetic Chemistry for Carbon Nanomaterials

Course Coordinator:

Akimitsu Narita

Description

This course mainly covers the synthetic methods for carbon nanomaterials, including fullerene derivatives, polyphenylenes, nanographenes, and graphene nanoribbons, from the perspectives of organic chemistry. Particular focus will be given on the synthesis of large polycyclic aromatic hydrocarbons (PAHs) developed over the past 100 years in the field of organic chemistry, which led to the recent bottom-up synthesis of atomically precise nanographenes and graphene nanoribbons. This course will also cover the related methods in polymer chemistry as well as the on-surface synthesis of nanocarbons, using the techniques of the surface science. Besides the synthetic methods, various spectroscopic and microscopic characterization methods available for the resulting carbon nanomaterials will be explained and their potential applications will be discussed.

Target Students

Students with background of organic chemistry who are interested in the synthesis of carbon nanomaterials.

Aim:

Students who complete this course will be able to: 1. Critically analyze papers on the synthesis of polycyclic aromatic hydrocarbon (PAH) and other carbon nanomaterials, with reference to a wide range of modern synthetic and characterization methods. 2. Discuss advantages and disadvantages of different synthetic approaches for carbon nanomaterials. 3. Synthesize and characterize known PAHs through several synthetic steps, following reported procedures.

Course Content:

The following topics will be covered, focusing on the synthesis and characterization methods and mainly taking examples from the recent literature.

1. Introduction: from polycyclic aromatic hydrocarbon (PAH) chemistry to bottom-up synthesis of carbon nanomaterials
2. Fully-benzenoid PAHs and extension to nanographenes
3. Not-fully-benzenoid PAHs
4. Heteroatom-incorporated PAHs
5. Open-shell PAHs
6. Helical PAHs
7. Polyphenylene polymers and dendrimers
8. From ladder polymers to graphene nanoribbons (GNRs)
9. On-surface synthesis of PAHs and GNRs
10. On-surface synthesis of two-dimensional carbon nanostructures
11. Fullerene derivatives
12. Other carbon nanomaterials

Course Type:

Elective

Credits:

2

Assessment:

1. In-class exercises throughout the term (20%) 2. Presentation to the class of a related paper of choice from the last five years (40%) 3. Laboratory reports (40%)

Reference Book:

Polyarenes I https://link.springer.com/book/10.1007/978-3-662-43379-9

From Polyphenylenes to Nanographenes and Graphene Nanoribbons https://link.springer.com/book/10.1007/978-3-319-64170-6

Synthetic Methods for Conjugated Polymers and Carbon Materials https://onlinelibrary.wiley.com/doi/book/10.1002/9783527695959

Prior Knowledge:

Undergraduate-level knowledge of general chemistry; Advanced-level knowledge of organic chemistry.

A227 Quantum Engineering – Simulation and Design

Course Coordinator:

Jason Twamley

Target Students
This course is targeted to students with a background in physics or any relevant discipline who have good knowledge of quantum mechanics and who wish to develop skills in the computational modelling of quantum machines. Advanced experience with Python is not required but some familiarity and competence with Python (such as taking the Python boot-camp) is required.

Description
This course explores the topic of integrated quantum devices. Such devices bring together different types of quantum systems which provide new functionality not possible within an individual quantum system. Such devices are used for fundamental quantum mechanic studies, quantum sensing, quantum communication and quantum computing. During the course students will develop "engineering" type skills towards learning how to design and model – theoretically and computationally, various types of composite quantum devices. Systems to be studied include integrated photonic with atomic, condensed matter and motional atomic systems including cavity quantum electrodynamics, cavity optomechanics, Nitrogen vacancy defects in diamond and levitated quantum systems.

The course consists of an initial section consisting of weekly lectures and computer labs. These labs are the central component of the course and during these labs students will learn computational techniques to study the properties of integrated quantum devices using python. The second section of the course consists of journal clubs and a final computational project with a poster presentation.

Aim:

Students who complete this course will be able to: a) Analyse and computationally model interacting quantum machines to uncover their unique quantum behaviours Assessment: One take home computational assignment and a final computational project b) Discuss and critically analyse recent scientific articles which focus on quantum machines Assessment: Presentation of a recent published paper of their choice to the class within a weekly journal club c) Communicate their research achievements in quantum engineering to formal and informal audiences. Assessment: Communication of their final computational project via the creation of a poster and an in-person poster explanation at a final course poster session

Course Content:

Each week consists of both lecture and computational lab work.

- Week 1: Introduction to quantum optics and the QuTip computational Python package, pure

quantum states, two level states visualized on the Bloch sphere, harmonic oscillator states visualized using Wigner functions
- Week 2: Dynamics of quantum systems: Time evolution of nonlinear quantum oscillators, dynamics of spins and simulation of the Stern Gerlach experiment
- Week 3: More advanced quantum optical systems: Introduction to cavity QED, derivation and simulation of the Jaynes Cummings/Rabi system, Photon Blockade, Collapse and revivals.
- Week 4: Study of open quantum systems including decoherence:
Study of the Lindblad master equation for a Qubit system
- Week 5: Application study: Two-level atomic Landau-Zener transitions and cavity-QED Photon-number Quantum Non-Demolition experiment
- Week 6: Introduction to optomechanical quantum systems: intro to optical cavities, derivation of Langevin equations and linearized Hamiltonian for optomechanical systems.
- Week 6: Cooling to the quantum ground state: review of optomechanical cooling, experimental results and theory/simulations.
- Week 7: More advanced analysis of optomechanics: coupled moment dynamics, study of the generation of entanglement between two spins in a mechanical system.
- Week 8: Review of magneto-mechanical systems. Final Project selections/ Journal Club Starts
- Week 9: Introduction to quantum sensing/parameter estimation. Journal Club and Project work.
- Week 10: Invited short seminar: Journal Club and Project Work.
- Week 11: Invited short seminar: Journal Club and Project Work.
- Week 12: Preparation of Posters reporting on Project Work.
- Week 13: Poster session on Project Work, involving all students and Zoom invited guests and other OIST faculty

Course Type:

Elective

Credits:

2

Assessment:

[30%] One mid-course take-home computational assignment (individual work)
[30%] Final project assignment (group work)
[20%] Presentation at a journal club
[20%] Attendance at each weekly computational lab.

Text Book:

Introduction to Quantum Optics
https://www.amazon.co.jp/-/en/Christopher-Gerry/dp/052152735X

Quantum Optics: An Introduction
https://www.amazon.co.jp/dp/0198566735/ref=cm_sw_em_r_mt_dp_AW0YM4GHBF3WXK6N77CY

Qutip: A quantum physics toolbox for Python. http://qutip.org

Prior Knowledge:

Undergraduate quantum mechanics (full year), experience is pre-required. This includes good knowledge of the quantum matrix mechanics for spin, Schrodinger equation (stationary and time-dependent), and the operator treatment of the quantum harmonic oscillator including creation and annihilation operators. Desirable pre-knowledge includes cavity quantum electrodynamics and atoms interacting with electromagnetic radiation. Python boot-camp is required but no other Python skills are required.

A273 Ultracold Quantum Gases

Course Coordinator:

Thomas Busch

Description:

The course will start out by introducing the fundamental ideas for cooling and trapping ultracold atoms and review the quantum mechanical framework that underlies the description of interacting matter waves in the ultracold regime. This will introduce the idea of degenerate Bose and Fermi gases, and in particular the concept of Bose-Einstein condensation.

After this the main properties of Bose-Einstein condensates will be discussed, including coherence and superfluidity, and for Fermi gases the physics of the BCS transition will be introduced. Conceptually important developments such as optical lattices, Feshbach resonances, artificial gauge fields and others will be explained in detail as well. New developments in the area of strongly correlated gases will be introduced and applications of cold atoms in quantum information or quantum metrology provide the final part of the course.

The course will mostly focus on the theoretical description of ultracold quantum gases, but regularly discuss experimental developments, which go with these.

Aim:

The course introduces the students to the field of ultracold quantum gases. The lectures are combined with a weekly journal club, where original publications related to the lecture are discussed. Students will learn some fundamental concepts and techniques used in ultracold atoms research and obtain an overview over the many directions this diverse field is developing into. At the end of the course the students should be able to read current scientific literature and discuss work with researchers in the area. Since the area of ultracold quantum gases has connections to many other fields of physics, especially condensed matter and optics, students will be able to pick up aspects of these as well.

Course Content:

1. Ultracold atomic gases: cooling and trapping

2. Bose-Einstein condensation and Fermi degeneracy in ideal gases

3. Interacting Bose-Einstein condensates: Gross-Pitaevskii equation.

4. Dynamics of Bose-Einstein condensates. Expanding and oscillating condensates.

5. Elementary excitations. Bogoliubov-De Gennes equations.

6. Two-dimensional Bose gases. Kosterlitz-Thouless transition.

7. Vortices and Superfluidity

8. One-dimensional systems: quasi-condensates and solitons

9. Strongly interacting 1D Bose gases. Impenetrable bosons.

10. Degenerate Fermi gases: BEC and BCS transitions

11. Optical lattices

12. Artificial Gauge fields

13. Applications in quantum information and metrology

Course Type:

Elective (Alternating Years)

Credits:

2

Assessment:

Homework: 50%, Project 25%, In-term tests, 25%.

Text Book:

Bose-Einstein Condensation in Dilute Gases C.J. Pethick and H. Smith (2002) Cambridge University Press

Bose-Einstein Condensation L.P. Pitaevskii and S. Stringari (2003) Oxford University Press

Fundamentals and New Frontiers of Bose--Einstein Condensation M. Ueda (2010) World Scientific

Reference Book:

Modern Quantum Mechanics, by J. J. Sakurai (1994) Addison-Wesley

Quantum Mechanics, by J.-L. Basdevant and J. Dalibard (2002) Springer

Prior Knowledge:

While the fundamental concepts of atomic physics and quantum mechanics that are required will be reviewed in the beginning of the course, basic prior knowledge of quantum mechanics is required (e.g. undergraduate quantum mechanics).

Companion course to A211 Advances in Atomic Physics

A303 Developmental Biology

Course Coordinator:

Ichiro Masai

Description:

This course introduces fundamental principles and key concepts in the developmental processes of animal organisms, by focusing on Drosophila embryonic development and vertebrate neural development as models, and will facilitate graduate students to reach a professional level of understanding of developmental biology. Furthermore, genetic tools for live imaging of fluorescence-labeled cells using Drosophila and zebrafish embryos will be introduced as practical exercises. The course also includes debate on specific topics in developmental biology by students and a writing exercise of mock-grant application. Some lecturers outside OIST will be invited to present particular special topics.

Aim:

This lecture series will introduce fundamental principles governing development of animal organisms and current research topics

Course Content:

1. Basic concepts of developmental biology, and introduction of model systems
2. Development of the Drosophila embryonic body plan
3. Organogenesis
4. Patterning of vertebrate body plan
5. Morphogenesis
6. Cell fate decision in the vertebrate nervous system
7. Current topics of neuronal specification and multipotency of neural stem cells
8. Axon guidance, target recognition
9. Synaptogenesis
10. A model for neurodegeneration in Drosophila

11. Debate of topics of developmental biology by students
12. Debate of topics of developmental biology by students
13. Debate of topics of developmental biology by students
14. Genetic tools for live imaging of fluorescence-labeled cells using Drosophila
15. Genetic tools for live imaging of fluorescence-labeled cells using zebrafish

Course Type:

Elective

Credits:

2

Assessment:

Participation 20%; Written Report 40%; Presentation 40%

Text Book:

Principles of Development 2 edn, Lewis Wolpert (2010) Oxford University Press

Developmental Biology 9 edn, Scott F. Gilbert (2010) Sinauer

Development of the Nervous System 3 edn, Sanes, Reh, Harris (2011) Academic Express

A304 Evolutionary Developmental Biology

Course Coordinator:

Noriyuki Satoh

Description:

The course presents the most recent theory and techniques in evolutionary and developmental biology with an emphasis on the underlying molecular genomics. Recent advances in decoding the genomes of various animals, plants and microbes will be followed, with a discussion on comparative genomics, the evolution of transcription factors and signal transaction molecules and their relation to the evolution of the various complex body plans present through history.

Aim:

To introduce basic concepts of Evo-Devo that are essential to understand the diversity of animal body plans.

Course Content:

1. Introduction (background, general concepts, etc)
2. History of animals (fossil records, phylogenic tree)
3. History of animals (genomics, molecular phylogeny)
4. Genetic toolkits (developmental concepts)
5. Genetic toolkits (Hox complex)
6. Genetic toolkits (genetic toolkits, animal design)
7. Building animals (lower metazoans)
8. Building animals (protostomes)
9. Building animals (deuterostome and vertebrates)
10. Evolution of toolkits (gene families)
11. Diversification of body plans (body axis)
12. Diversification of body plans (conserved and derived body plans)
13. Evolution of morphological novelties
14. Species diversification
15. Phylum diversification

Course Type:

Elective

Credits:

2

Assessment:

Homework (20%), Written reports (4 x 20%).

Text Book:

From DNA to Diversity, 2 edn, by Carroll, Grenier and Weatherbee (2005) Blackwell.

A306 Neuroethology

Course Coordinator:

Yoko Yazaki-Sugiyama

Description:

The course provides an understanding of the neuronal mechanisms that underlie animal behavior. We will study the neuronal mechanisms for specialized animal behaviors such as sensory processing, motor pattern generation, and learning by reading original papers, which also provide an understanding of experimental technique. The course further discusses the evolutionary strategy and the biological ideas of animal behavior and underlying neuronal mechanisms.

Aim:

To introduce an understanding of the neuronal mechanisms that control complex animal behavior.

Course Content:

1. Introduction (Basic Neurophysiology and neuronal circuits)
2. Sensory information I: Visual and Auditory (map formation, plasticity and critical period, etc.)
3. Sensory information II: Olfactory (Chemical) and other senses
4. Sensory perception and integration I (Echolocation, Sound localization, etc.)
5. Sensory perception and integration II (Sensory navigation, etc.)
6. Motor control I (Stereotyped behavior)
7. Motor control II (Central pattern generator)
8. Sexually dimorphic behavior
9. Learning I (Learning and memory)
10. Learning II (Associative learning)
11. Learning III (Sensory motor learning during development)
12. Learning VI (Spatial navigation)
13. Behavioral plasticity and the critical period
14. Recent techniques in neuroethology

Course Type:

Elective

Credits:

2

Assessment:

Homework, 20%; Written reports, 4 x 20%.

Text Book:

Behavioral Neurobiology, by Thomas J Carew (2000) Sinauer

Prior Knowledge:

Required: B26 Introduction to Neuroscience or similar (demonstrated by passing the B26 exam)

A307 Molecular Oncology and Cell Signalling

Course Coordinator:

Tadashi Yamamoto

Description:

This course consists of lectures and exercises. First, students learn, through lectures, recent progress in cancer research and the mechanism of carcinogenesis based on the molecular and cellular functions of oncogenes and anti-oncogenes. Further, students will learn the relevance of signal transduction, cell cycle progression, cell adhesion, and gene regulation to tumor development and are encouraged to simulate effective methods of diagnosis and treatment of cancer. Further, through exercises, students will consider the relevance of genome sciences and systems biology to cancer research. Students are encouraged to refer to the textbook and to papers from the current literature. The course will also present special novel and important topics from year to year.

Aim:

This advanced course aims to develop a deep understanding of tumor development, based on recent research developments in the molecular and cellular biology of cancer.

Course Content:

1. Historical background of molecular oncology

2. Viruses, chemical carcinogens, and tumor development
3. RNA tumor viruses and oncogenes
4. Discovery of anti-oncogenes
5. Regulation of signal transduction and cell cycle progression by oncogenes and anti-oncogenes
6. Roles of oncogenes and anti-oncogenes in normal physiology
7. Molecular mechanisms of metastasis
8. Genome, proteome, metabolome, and cancer
9. Animal models of cancer
10. Drug development for cancer treatment
11. Cancer stem cells
12. microRNA and cancer development
13. Genome sciences in cancer research
14. Systems biology in cancer research

Course Type:

Elective

Credits:

2

Assessment:

Oral presentation of paper, 50%; Research report, 50%.

Text Book:

The Biology of Cancer, by Weinberg (2006) Garland Science

Molecular Biology of the Cell, 5 ed, by Alberts, Johnson, Lewis, Raff, Roberts and Walter (2007) Garland Science

Reference Book:

The Molecules of Life, by Kuriyan, Konforti, and Wemmer (2012) Garland Science

Biochemistry, 7 ed, by Berg, Tymoczko, and Stryer (2010) WH Freeman & Company

Prior Knowledge:

Requires at least advanced undergraduate level Cell Biology and Genetics or similar background knowledge

A308 Epigenetics

Course Coordinator:

Hidetoshi Saze

Description:

Epigenetic regulation of gene activity is essential for development and response to environmental changes in living organisms. This course introduces fundamental principles and key concepts of epigenetics, and original research publications contributed to understanding the mechanism underlying the epigenetic phenomena will be reviewed. Lecturers from outside OIST may be invited for specific topics.

Aim:

This course provides an overview of the principles of epigenetics to students with background of molecular biology and genetics.

Course Content:

1. Introduction to Epigenetics
2. Histone variants and modifications
3. DNA methylation
4. RNA interference and small RNA
5. Regulation of chromosome and chromatin structure
6. Transposable elements and genome evolution I
7. Transposable elements and genome evolution II
8. Epigenetic regulation of development I
9. Epigenetic regulation of development II
10. Genome imprinting
11. Dosage compensation I
12. Dosage compensation II
13. Epigenetic reprogramming and stem cells
14. Epigenetics and disease

15. Epigenomics

Course Type:

Elective

Credits:

2

Assessment:

Participation 50%; Presentation, 50%.

Text Book:

Epigenetics, by Allis, Jenuwein, Reinberg, Caparros (2006) Cold Spring Harbor Laboratory Press

Reference Book:

Molecular Biology of the Cell, 5 edn, by Alberts et al. (2007) Garland Science

Introduction to Genetic Analysis, 10 edn, by Griffiths et al. (2010) W.H. Freeman and Company

Prior Knowledge:

Requires at least advanced undergraduate level Cell Biology and Genetics or similar background knowledge

A310 Computational Neuroscience

Course Coordinator:

Erik De Schutter

Description:

Computational neuroscience has a rich history going back to the original Hodgkin-Huxley model of the action potential and the work of Wilfrid Rall on cable theory and passive dendrites. More recently networks consisting of simple integrate-and-fire neurons have become popular. Nowadays standard simulator software exists to apply these modeling methods, which can then be used to interpret and predict experimental findings.

This course introduces some standard modeling methods with an emphasis on simulation of single neurons and synapses and an introduction to integrate-and-fire networks. Each theoretical topic is linked to one or more seminal papers that will be discussed in class. A number of simple exercises using the NEURON simulator will demonstrate single neuron and synapse modeling.

Aim:

This course introduces basic concepts and methods of computational neuroscience based on theory and a sampling of important scientific papers.

Course Content:

1. Introduction and the NEURON simulator
2. Basic concepts and the membrane equation
3. Linear cable theory
4. Passive dendrites
5. Modeling exercises 1
6. Synapses and passive synaptic integration
7. Ion channels and the Hodgkin-Huxley model
8. Neuronal excitability and phase space analysis
9. Other ion channels
10. Modeling exercises 2
11. Reaction-diffusion modeling and calcium dynamics
12. Nonlinear and adaptive integrate-and-fire neurons
13. Neuronal populations and network modeling
14. Synaptic plasticity and learning

Course Type:

Elective

Credits:

2

Assessment:

Active participation to textbook discussions in class (40%), reports on modeling papers (40%), written exercises (20%).

Text Book:

Biophysics of Computation, by Christof Koch (1999) Oxford Press

Neural Dynamics: From Single Neurons to Networks and Models of Cognition, by Wulram Gerstner, Werner M. Kistler, Richard Naud and Liam Paninski (Cambridge University Press 2014)

Reference Book:

Computational Modeling Methods for Neuroscientists, edited by Erik De Schutter (MIT Press 2010)

Prior Knowledge:

Requires prior passes in OIST courses B22 Computational Methods and B26 Introduction to Neuroscience, or similar background knowledge in computational methods, programming, mathematics, and neuroscience.

A311 Cellular Aging and Human Longevity

Course Coordinator:

Mitsuhiro Yanagida

Description:

Cells undergo aging and have limited lifespans. This lecture course covers the genetic, molecular, and cellular mechanisms that control cellular aging and that affect the lengths of organismal lifespans. Various strategies for investigating human longevity are also discussed.

Aim:

This course provides a current overview of cellular aging and human longevity.

Course Content:

1. What is gerontology?
2. How to measure aging
3. Longevity in different organisms
4. Methods 1, On human aging 1
5. Methods 2, On human aging 2
6. Cellular aging, Mechanism of aging
7. Genetics, Genetics of aging
8. Plant aging
9. Human aging

10. Physiology: Body, Skin, Senses, etc.
11. Age related diseases
12. Diabetes, Frailty, Brain, Cardiovascular, Endocrine
13. Modulating aging & Longevity

Course Type:

Elective

Credits:

2

Assessment:

Requirements; Reports, Oral Discussion, Participation of Experimental demonstration using apparatus (LC-MS)

Text Book:

Biology of aging Roger McDonald 2014

https://www.amazon.co.jp/Biology-Aging-Roger-B-McDonald/dp/0815342136

Prior Knowledge:

Requires at least advanced undergraduate level Cell Biology and Genetics or similar background knowledge

A312 Sensory Systems

Course Coordinator:

Izumi Fukunaga

Description:

The course will cover general concepts and specific modalities as detailed in the table below. Classes alternate between lecture-style teaching and a journal club. Each lecture will be based on a textbook chapter (Kandel et al’s Principles of Neural Sciences, in combination with other specialised books described in the “Textbooks” section) to cover basic and broad topics, but will also serve as an opportunity to introduce concepts required to understand the research article associated with the lecture.

Aim:

The course is structured for students who would like to know about sensory systems in the brain at an advanced level. The overall aim is expose students to research-level materials, but starting from basic concepts. Topics will include specialisations as well as common principles found in the mechanisms of sensory perception, and will cover the somatosensory, visual, auditory, olfactory systems from transduction to higher cognitive functions. In parallel, the course aims to develop students' ability to read and discuss primary research articles, to give students an exposure to some of the latest techniques and developments.

Course Content:

The course will cover general concepts and specific modalities as detailed in the table below. Classes alternate between a lecture-style teaching and a journal club. Each lecture will be based on a textbook chapter (Kandel et al's Principles of Neural Sciences, in combination with other, specialised books described in the "Textbooks" section) to cover basic and broad topics, but will also serve as an opportunity to introduce concepts required to understand the research article associated with the lecture.

Schedule:

Session, Title, Type, Summary of contents

1 (wk1), Overview, lecture/intro, Motivation; Modality, basic organisation: transduction, pathways, maps, integration, perception

2 (wk1), Sensory coding, lecture/intro, Relationship between a physical stimulus and sensation; intensity, threshold, adaptation, effect of background, discriminability

3 (wk2), Somatosensory system I, lecture/intro, Transduction (general mechano sensing), texture representation. -Special topic (extra lecture): Active Sensing by Dr Sander Lindeman

4(wk2), Somatosensory system I, Journal club, Active spatial perception in the vibrissa scanning sensorimotor system by Mehta, Whitmer, Figueroa, Williams & Kleinfeld 2007

5(wk3), Somatosensory system II, lecture/intro, Somatosensory maps, higher processing.Special topic (extra lecture): Object localization and discrimination by Dr Sander Lindeman

6(wk3), Somatosensory system II, Journal club, Sparse optical microstimulation in barrel cortex drives learned behaviour in freely moving mice. Huber et al., 2008.

7(wk4), Hearing I, lecture/intro, Ear, sound transduction, tonotopy, phase locking and sound localization.

8(wk4), Hearing I, Journal club, A circuit for detection of interaural time differences in the brain stem of the barn owl. Carr and Konishi, 1990

9(wk5), Hearing II, lecture/intro, Adaptation, demixing, higher processing (language)

10(wk5), Hearing II, Journal club, Selective cortical representation of attended speaker in multi-talker speech perception. Mesgarani & Chang. 2012

11(wk6), Vision I, lecture/intro, Light transduction, eye, retinotopy, filtering in the retina

12(wk6), Vision I, Journal club, Wiring specificity in the direction-selectivity circuit of the retina by Briggman, Helmstaedter & Denk, 2011

13(wk7), Vision II, lecture/intro,

14(wk7), Vision II, Journal club, Explicit information for category-orthogonal object properties increases along the ventral stream by Hong, Yamins, Majaj & DiCarlo 2016

15(wk8), Chemical Senses I, lecture/intro, Olfactory stimuli and receptors, glomerular maps, combinatorial code.

16(wk8), Chemical Senses I, Journal club, A novel multigene family may encode odorant receptors: A molecular basis for odor recognition. Buck and Axel. 1991

17(wk9), Chemical Senses II, lecture/intro, Higher olfactory processing – processing in the olfactory bulb and cortical areas.

18(wk9), Chemical Senses II, Journal club, Random convergence of olfactory inputs in the Drosophila mushroom body by Caron, Ruta, Abbott & Axel, 2013

19(wk10), Chemical Senses III, lecture/intro, Gustation – taste receptors, pathways.Coffee break – Special topic (extra lecture): Convergence of taste and olfactory information by Dr Cary Zhang.

20(wk10), Chemical Senses III, Journal club, Candidate Taste Receptors in Drosophila by Clybe, Warr and Carlson, 2000.

Course Type:

Elective

Credits:

2

Assessment:

Careful reading of the research article set for each journal club; Each student is asked to write a 1-page summary of the paper in their own words (Homework: 70%). The summary should include the context/rationale for the experiments, methods, results and

Text Book:

1. Principles of Neural Science (MIT Press) by Kandel, Schwartz, Jessell, Siegelbaum, Hudspeth

2. Auditory Neuroscience (MIT Press) by Schnupp, Nelken and King

3. Principles of Neural Design (MIT Press) by Peter Sterling and Simon Laughlin

Reference Book:

1. Vision by David Marr

Prior Knowledge:

The course is aimed at students with a background in neuroscience (either at the BSc/MSc level or having successfully completed some of the basic neuroscience course offered at OIST). It assumes knowledge in cellular neurophysiology and neuroanatomy. Most relevant courses at OIST will include: B26 (Introduction to Neuroscience, required); B05 (Cellular Neurobiology; desirable), A405 (Emerging technologies in life sciences; desirable), B09 (Learning and behaviour; desirable), A310

(Computational neuroscience; highly desirable).
B26 is the most important (in terms of subject matters listed on the course’s website), so a pass in this course (or in the exam, without taking the course) is a pre-requisite.

A313 Cognitive Neurorobotics

Course Coordinator:

Jun Tani

Description:

The primary objective of this course is to understand the principles of embodied cognition by taking a synthetic neurorobotics modeling approach. For this purpose, the course offers an introduction of related interdisciplinary knowledge in artificial intelligence and robotics, phenomenology, cognitive neuroscience, psychology, and deep and dynamic neural network models. Special focus is given to hands-on neurorobotics experiments and related term projects.

Aim:

This course aims to provide an overview of the synthetic approach to understand embodied cognition by using deep dynamic neural network models and robotics platforms.

Course Content:

1. Introduction: cognitive neurorobotics study
2. Cognitism: compositionality and symbol grounding problem
3. Phenomenology: consciousness, free will and embodied minds
4. Cognitive neuroscience I: hierarchy in brains for perception and action
5. Cognitive neuroscience II: Integrating perception and action via top-down and bottom-up interaction
6. Affordance and developmental psychology
7. Nonlinear dynamical systems I: Discrete time system
8. Nonlinear dynamical systems II: Continuous time system
9. Neural network model I: 3-layered perceptron, recurrent neural network
10. Neural network model II: deep learning, variational Bayes

11. Neurorobotics I: affordance & motor schema

12. Neurorobotics II: higher-order cognition, meta-cognition, and consciousness

13. Neurorobotics III: hands-on experiments in lab

14. Paper reading for neurorobotics and embodied cognition I

15. Paper reading for neurorobotics and embodied cognition II

Course Type:

Elective

Credits:

2

Assessment:

Mid-term exam: 40%, final term project report: 60%.

Text Book:

Exploring robotic minds: actions, symbols, and consciousness as self-organizing dynamic phenomena. Jun Tani (2016) Oxford University Press.

Prior Knowledge:

Basic mathematical knowledge for the calculus of vectors and matrices and the concept of differential equations are assumed. Programming experience in Python, C or C++ is also required.

A314 Neurobiology of Learning and Memory I

Course Coordinator:

Jeff Wickens

Description:

The aim of this course is to engage students in thinking about and discussing fundamental issues in research on neural mechanisms of learning and memory. Topics include the neural mechanisms of learning, memory, emotion, and addictive behavior. Students will be expected to read original reports including classical papers as well as recent advances. The course includes an experimental requirement in which students must design and conduct an experiment related to learning and memory mechanisms of the brain.

Aim:

The aim of this course is to engage students in thinking about and discussing fundamental issues in research on neural mechanisms of learning and memory.

Course Content:

1. Historical perspectives on learning and memory. Classification of learning and memory functions. Theories of memory and learning.
2. Experimental models of memory. Developmental plasticity. Anatomical plasticity. Conditioned reflexes. Imprinting. Extinction. Forgetting.
3. Synaptic plasticity: Homosynaptic and heterosynaptic plasticity, long-term potentiation, long-term depression. Spike-timing dependent plasticity.
4. Cellular mechanisms of synaptic plasticity. Intracellular messages, retrograde messages, receptor phosphorylation, protein synthesis, gene expression, synaptic tagging. Amino acid receptors. AMPA, NMDA, mGluR, nitric oxide.
5. Invertebrate models. Aplysia, honey bees, drosophila. Sensitization of reflexes.
6. Neural circuits for reinforcement learning. Substrates of reward and punishment.
7. Neuromodulation and memory. Dopamine, acetylcholine, serotonin, other neuromodulators. Volume transmission.
8. Cellular mechanisms of reinforcement. Neurochemical basis. Habits, action-outcome learning, behavioral flexibility.
9. Memory and aging. Amnesia. Memory enhancers.
10. Neurochemistry of emotion. Drugs and mood. Addictive behavior.

Course Type:

Elective

Credits:

2

Assessment:

Students will be required to: (i) prepare and present a lecture on the neural basis of a higher integrative function (40%); (ii) design and conduct an experiment on learning and memory (40%); (iii) participate in class discussions (20%).

Text Book:

Selected original papers. Selected chapters from the online course, https://nba.uth.tmc.edu/neuroscience/s1/iend.html

Prior Knowledge:

Students should have previously taken at least two basic courses in neuroscience: B26 Introduction to Neuroscience, and at least one other basic neuroscience course; or have completed the equivalent by documented self-directed study

A315 Quantitative Approaches to Studying Naturalistic Animal Behavior

Course Coordinator:

Sam Reiter

Description:

Naturalistic animal behavior is complex. Traditionally, there have been two general approaches to dealing with this complexity. One approach, common in psychology, is to simplify an animal's environment, or its movements, in order to make precise measurements. Another approach, taken by ethologists, is to study complex naturalistic behaviors directly. In many cases this choice has forced researchers to give up on quantitative rigor. Recent breakthroughs in camera technology and computational techniques open up the possibility of merging these approaches. We can now describe naturalistic behavior quantitatively.

Students will be expected to engage with the material, and discuss with their peers and the instructor during class. Homework is in the form of reading papers that will be discussed the following class (~2 hours/week), and in learning the background concepts necessary to understand and discuss the papers (~2 hours/week). Projects ideas will be proposed in writing ~2/3 way through the course (citing the relevant literature), and project results will be presented to the class. Projects will be assessed based on how they demonstrate the student's mastery of the relevant course material, creativity, and on presentation quality.

Aim:

This course is aimed at students looking at animals and wondering how to capture and describe their behavior in the best way. Students will learn the practical skills of how to record and track animal behavior using modern tools, and the pros and cons of different approaches. We will then discuss recent work on the open question of what we should do now that we can track so much. We will introduce different approaches to modeling individual and collective animal behavior, as well as the relationship between behavior and the brain. Students should choose this course because for a wide range of questions related to neuroscience, ecology, marine biology, and biophysics there is no shortcut to grappling with the question of animal behavior (at least I haven't found one).

Course Content:

Background

Traditional approaches to ethology and neuroscience
Basics of data analysis, machine learning, deep neural nets
Basics of optics, computer vision, camera design

Quantifying movement

Image filtering and morphological operations
Marker based and marker-less pose estimation
2.5 dimensional imaging (RGB-D)
Semantic segmentation
Tracking collective animal behavior

Describing behavior

Eigenworms and the dynamical systems view
Mouse behavioral syllables and Markov models
Drosophila behavioral space and nonlinear dimensionality reduction
Supervised learning approaches (e.g. boosted decision trees)
Drosophila social behavior and generalized linear models

Linking behavior to neural activity

Traditional brain-behavior correlations: hippocampal cell types
Imaging neural activity in freely moving C. elegans
Selective neural activation-behavior screens in Drosophila
Cephalopod skin patterning dynamics
Mouse basal ganglia and motor control

Collective behavior

Boids model
Experimental manipulation of animal collectives
Fish schooling and deep attention networks
Noise-induced schooling

Course Type:

Elective

Credits:

2

Assessment:

Participation in class discussions 50%, Project 50%.

Reference Book:

Deep Learning with Python, Chollet

Multiple View Geometry in Computer Vision, Hartley and Zisserman

Prior Knowledge:

The material builds on basic knowledge of linear algebra, machine learning, neuroscience, and behavioral ecology. A background in any of these topics isn't required if a student is willing to learn the relevant concepts as they arise, in preparation for discussing papers in class. Suggested to take B26 first.

A316 Neuronal Molecular Signaling

Course Coordinator:

Marco Terenzio

Description:

During this course we will review receptor signaling and its associated transcriptional responses as well as peripheral local translation of signaling molecules. We will discuss the active mechanisms of transport utilized by the neurons to convey organelles and signaling complexes from the plasma membrane to the nucleus with a focus on the dynein machinery and retrograde axonal transport. We will then review the current state of progress in the understanding of the link between defects in axonal trafficking and neurological diseases and between local translation of the response to axonal injury and the induction of a regenerative program. In this context we will discuss both the peripheral and central nervous system. This course will include a practical session of imagining of axonal transport, where the students will be exposed to the most recent techniques for imaging and quantifying intracellular transport.

This course is targeted to students who want to deepen their understanding of neuronal axonal signaling and get some hands-on experience in intracellular trafficking live imaging.

Aim:

The aim of this course is to discuss some of the major molecular signaling pathways from the periphery to the cell bodies in neurons. The students are expected to achieve a basic understanding of long-range molecular signaling in neurons and the experimental techniques available for its investigation.

Course Content:

1. Receptor signaling in neurons
2. Second messengers and intracellular signaling cascades
3. Peripheral local translation
4. Journal club held by students part1
5. Intracellular molecular transport – anterograde transport
6. Intracellular molecular transport – retrograde transport
7. Neuronal transcriptional responses
8. Neurodegenerative diseases linked to transport defects
9. Journal club held by students part2
10. Signaling mechanisms in injury and regeneration
11. Experimental techniques to image axonal transport and translation
12. Laboratory on axonal transport (cell culture and preparation)
13. Laboratory on axonal transport (imaging)
14 Laboratory on axonal transport (data analysis)
15. Final Exam

Course Type:

Elective

Credits:

2

Assessment:

Practical laboratory course + data analysis 20%; Presentation 50%; Final exam 30%

Text Book:

Purves, Augustine, Fitzpatrick, Hall, Lamantia and White: Neuroscience, 5th or 6th edition

Prior Knowledge:

This course is an advanced course for neuroscience. It assumes a basic knowledge of cellular biology and neurobiology.

Passing B26 Introduction to Neuroscience or equivalent previous course work elsewhere is required.

A317 Fish Biology and Evolution

Course Coordinator:

Vincent Laudet

Description:

Fish are an integral part of our societies and culture. In addition to their economic value, they have considerable cultural and symbolic value. However, because of their aquatic way of life, in an environment which is almost completely foreign to us, their zoological distance from us, from their cold blood and their bodies covered with scales, we often consider them as dumb creatures of little interest except their delicate flesh and sometimes their beautiful colors.

And yet! What diversity! What incredible abilities! What fantastic adaptations! Fish have conquered virtually all the aquatic environments of our planet, even the most extreme. They are capable of elaborate behaviors and of complex social interactions and they can express individual characters like shyness or boldness. Like birds, they communicate with elaborate sounds. We have too largely ignored these fascinating animals because we misunderstand them and their environment. This course will therefore consider in general terms the biology and evolution of fish from either marine or freshwater origin. It will allow the students to better understand how fish work, how they evolve, how they adapt to diverse environments and the challenges they face.

Aim:

The students must be able to understand the value of integrated approach, that is using several scientific disciplines together to solve a biological question. - They should also understand the value of comparing the outcome of several biological models - They will learn about the diversity of fish and should never again underestimate the abilities of these animals - They will learn the constraints and bias that act on animals and shape their evolutionary trajectories - They should understand the importance of protecting fish

Course Content:

Introduction: Did you say fish? (2 hr)
- What is a fish?
- The main fish models

PART 1: The origin and evolution of fish (6 hr)
- Actinopterygian fish phylogeny
- More genes in fish
- Fish radiations

PART 2: How fish work (10 hr)
- Locomotion
- Feeding
- Energy and metabolism
- Basic physiology
- Pigmentation
- Behavior

PART 3: Sexy Fish (10 hr)
- Migrations for reproduction
- Sex determination

- Courtship
- Development
- Parental care
- Perversities

PART 4: Extreme fish (6 hr)
- Life in the cold
- Life in the heat
- Life in the deep
- Life outside water

PART 5: The future of fish (6 hr)
- Fisheries and Aquaculture
- Pollution
- Climate change

Course Type:

Elective

Credits:

2

Assessment:

50% will be a bibliographical project with a 5 page report and a 10 min presentation; 50% will be a classical exam (with document allowed) during which the students will have to analyse the figures of a paper.

Text Book:

The Diversity of Fishes: Biology, Evolution, and Ecology by Gene Helfman Bruce B. Collette Douglas E. Facey, Brian W. Bowen. Wiley-Blackwell

Reference Book:

Essential Fish Biology: Diversity, Structure, and Function (English Edition) by Derek Burton and Margaret Burton Oxford Univ Press

Marine Biology. Function, Biodiversity, Ecology Jeffrey S Levinton Oxford Univ. Press

The Physiology of Fishes. Fifth edition Edited by Suzanne Currie and David H. Evans CRC Press

Fishes of the World. Fifth edition Joseph S. Nelson Wiley

Ecology of Fishes on Coral Reefs. Edited by Camilo Mora Cambridge Univ. Press

Prior Knowledge:

The students must have taken the course B34 "Coral Reef Biology and Ecology"
Preferably they will also have taken basic introductory course on ecology/evolution.

A318 Neurobiology of Learning and Memory II

Course Coordinator:

Kazumasa Tanaka

Description:

In this course, we will go over fundamental issues in neural mechanisms of learning and memory, with a focus on memory. In addition to lecture sessions, we will have a journal club and a study section. In the first week of the course, the instructor will list papers for the journal club. Each student chooses one of them and discusses it during the later session. In the study section, students will practice writing a research proposal (as a format of grant) and how to score proposals. The instruction will be provided in the first session.

Aim:

Through the course, students will have fundamental knowledge in memory studies and experience flavors of both critical/productive thinking when reading papers. Students interested in memory and have basic knowledge of neuroscience (pre-requisite: B26 Introduction to Neuroscience).

Course Content:

1. Introduction and goals of this course
2. Synapse and memory
3. Approaches in memory studies
4. Linking synaptic plasticity and memory 1
5. Linking synaptic plasticity and memory 2
6. Journal Club
Each student chooses a paper for discussion in the class. A list of papers will be given.
7. Systems consolidation
8. Anatomy of the Hippocampus and surrounding areas
9. Adult neurogenesis (taught by Viviane Saito)
10. Hippocampal physiology 1
11. Hippocampal physiology 2
12. Study Section
Discuss and score research proposals
13. Final exam

Course Type:

Elective

Credits:

2

Assessment:

short answer quizzes during term (40%), performance during journal club (10%), performance in research proposal/study section (10% /10%), and final exam (30%)

Reference Book:

The Neurobiology of Learning and Memory (3rd edition) by Jerry W. Rudy

The Hippocampus Book by Per Andersen, Richard Morris, David Amaral, Tim Bliss & John O'Keefe

Prior Knowledge:

Required to pass B26 Introduction to Neuroscience.

A319 Microbial Evolution and Cell Biology

Course Coordinator:

Filip Husnik

Target Students

The students should have a background in biology and biochemistry and be interested in learning more about single-celled organisms. Apart from students with background in evolutionary biology, molecular cell biology, ecology, marine biology, microbiology, biochemistry, developmental biology, etc., the course can be taken also by out-of-field students who would like to get a glimpse of evolution of life and microbial diversity.

Description

Most of the genetic, cellular, and biochemical diversity of life rests within single-celled organisms, prokaryotes (bacteria and archaea) and microbial eukaryotes (protists). Bacteria and archaea not only account for over 3.5 billion years of evolution, but also played a crucial role in the origin of the

first eukaryotic-like (protist) cells approximately two billion years ago. However, most of our knowledge about evolution and cell biology (and how we frame it) comes from a small subset of eukaryotic diversity -- multicellular animals and plants. During the course, we will take a broad view of the immense diversity of single-celled organisms (both prokaryotes and eukaryotes), focusing on their evolution, ecology, genetics, biochemistry, and cell biology. We will explore their evolutionary history and highlight major cellular innovations that occurred in single-celled organisms during the evolution of life.
The successful student will be able to describe differences in evolution and cell biology of single-celled organisms as opposed to multicellular organisms. The course is designed partly to fix biases that students often acquire from working with 'model organisms' that are mostly multicellular (animals and plants) and partly to showcase the immense diversity of microorganisms. It is thus not a traditional microbiology course, but it rather focuses on selected broadly interesting aspects of microbial evolution and cell biology such as major evolutionary transitions and cellular innovations. The students should gain knowledge about the evolutionary 'baggage' from our single-celled history that constrains the functioning of any modern cell, and be able to apply the knowledge in their own projects.

Aim:

At the end of the course, a successful student will be able to:

SLO #1: Analyze and critically evaluate a scientific paper about single-celled organisms, explain its main results to its peers, and reply to questions. Deliverable: student presentation on a selected evolutionary cell biology article Assessment criteria: understanding the main take home messages of the paper (30%), clear presentation (20%), critically evaluating potential issues in the methods-results-discussion sections (20%), and responding to questions from the audience (30%)

SLO #2: Design a scientific project (using literature review) that would target a fundamental question concerning single-celled organisms. Deliverable: written student project (3 pages, incl. 1-2 small figures) in the form of a small grant application (introduction, hypothesis, key question, 2-3 main goals, methods, broad implications) Assessment criteria: the grant application follows requirements (40%), literature review (20%), main goals target the key question (20%), methods and feasibility (20%)

SLO #3: Analyze own results from laboratory work on microorganisms and contrast the results with data from other students. Deliverable: written protocols from laboratory exercises, including figures and discussion about negative/poor results Assessment criteria: main results clearly highlighted (50%), figures/drawings/plots represent main findings and include correct legends (25%), discussion about potential issues and troubleshooting (25%)

SLO #4: Describe the main differences in evolution and cell biology of single-celled organisms as opposed to multicellular organisms. Deliverable: final exam Assessment criteria: 10 simple questions requiring a short answer (70%), 2 questions requiring a longer answer and/or a drawing (30%)

Course Content:

Theoretical part
1. What are cells and how they came to be the way they are (Evolutionary Cell Biology)
2. Origin of life, RNA world, genetic codes, and first 'prokaryotic' cells (LUCA)
3. Introduction to population genetics and phylogenetics (selection, mutation, drift, Muller's ratchet, constructive neutral evolution, interpreting phylogenetic trees)
4. Evolution and diversity of bacteria and archaea

5. Asgard archaea, mitochondria, and the origin of the eukaryotic cell (LECA)
6. Mitochondrial evolution (ATP, hydrogenosomes/mitosomes, etc.)
7. Photosynthesis and diversification of plastids
8. Tree of life and eukaryotic supergroups (SAR, Excavata, Amoebozoa, Opisthokonta, Archaeplastida, and orphan clades)
9. Chemosynthesis and life in deep sea and hydrothermal vents
10. Prokaryotic vs. eukaryotic metabolism and lifestyles (phototrophy, heterotrophy, mixotrophy)
11. Major eukaryotic innovations (endomembrane system, nucleus, phagocytosis, cytoskeleton)
12. Microbial genomics, sex, and horizontal gene transfer
13. Evolution of multicellularity

Student Presentations
15 min presentation by every student about a selected paper (+10 min discussion). Students will be provided with a list of possible papers to present, including options for out-of-field students.

Laboratory exercises
Cultivation-dependent and cultivation-independent methods for studying microorganisms
a) Sampling microorganisms (marine, fresh-water, soil, animal-associated, etc.)
b) Culturing single-celled eukaryotes (phototrophs and predators)
c) Preparing a Winogradsky column with prokaryotes
d) Light and fluorescent microscopy (microorganisms sampled during field work and/or cultured)
e) Genome-resolved metagenomics: Nanopore/Illumina sequencing and real-time bioinformatics analysis of microbial diversity

Course Type:

Elective

Credits:

2

Assessment:

30% participation and discussion, 20% presentation, 25% mid-term project, 25% final exam

Reference Book:

One plus one equals one; John Archibald, Oxford University Press 2014

The tangled tree: A radical new history of life; David Quammen, Simon & Schuster 2018

I contain multitudes: The microbes within us and a grander view of life; Ed Yong, Ecco Press 2016

Prior Knowledge:

Basic understanding of evolutionary and cell biology at the undergraduate level is assumed. The following courses offered at OIST are recommended to students who first want to review their knowledge: Molecular Biology of the Cell (B27) and Evolution (B37) [or Molecular Evolution (B23)].

A401 Controversies in Science

Course Coordinator:

Gordon Arbuthnott

Description:

The course Controversies in Science aims to develop critical thinking and argument, essential skills for effective independent scientists. The course will be flexible in content and presentation. Invited lecturers will present topics of some controversy or recent interest in science and lead debates by the students. We will also look at some historical controversies in different fields such as neuroscience and genetics, in which we will assign students to take sides by reading only one side of a specific argument and encourage them to discuss the issue and arrive at a resolution in class.

Aim:

This course aims to develop the argument and critical powers of scientists by examining the scientific process and its relation to knowledge, and looking at a wide range of topics of moral controversies in science.

Course Content:

1. Neuroscience started in a disagreement
2. Scary influence at a distance
3. Paradigm shifts: the real scientific advances are not predictable
4. Some other theories of scientific knowledge and its advancement
5. Conclusions: science as a social enterprise

Course Type:

Elective

Credits:

2

Assessment:

Participation and contribution to discussion and debate.

Text Book:

Scientific Controversies: Case Studies in the Resolution and Closure of Disputes in Science and Technology, by Engelhardt and Caplan (1987) Cambridge University Press

Reference Book:

Doubt: A History: The Great Doubters and Their Legacy of Innovation from Socrates and Jesus to Thomas Jefferson and Emily Dickinson, by JW Hecht (2004)

A405 Emerging Technologies in Life Sciences

Course Coordinator:

Ichiro Maruyama

Description:

This course is designed to provide a broad, advanced-level coverage of modern technologies in life sciences for first year PhD students. Topics include recombinant DNA technologies, polymerase chain reactions, DNA sequencing, microfluidics, fluorescent proteins, optical microscopy, mass spectrometry among others. Lectures will draw from historical and current research literature with emphasis on development of technologies as life sciences make progresses. A major goal of this course is to help graduate students accustomed to inventing novel technologies, improving existing technologies, or formulating a novel idea in the field of life sciences.

Aim:

This course introduces cutting-edge technologies in life science.

Course Content:

1. Course Introduction & Genetic engineering
2. Classical nucleotide sequencing
3. Next-generation nucleotide sequencing
4. Fluorescent proteins
5. Microfluidics
6. Fluorescence light microscopy (confocal, TIRF, spinning disk, etc.)
7. Mass spectroscopy
8. CRSPR/Cas9
9. Super resolution microscopy
10. PCR & Isothermal amplification

11. As requested.

Course Type:

Elective

Credits:

2

Assessment:

Final grades will be determined by listed criteria described below. Scores will be converted to letter grades, where A: 100-90%, B: 89-80%, C: 79-60%, and F: below 60%

A409 Electron Microscopy

Course Coordinator:

Matthias Wolf

Description:

The course is designed as a mix of introductions into selected topics in the theory of transmission electron microscopy followed by practical demonstrations and hands-on exercises, which provide an opportunity to comprehend the concepts by experimenting with commonly-used image processing software. Students will be required to read and digest scientific papers for a subset of lecture topics on their own, which will subsequently be discussed jointly during student presentations with the goal to immerse them into the subject without passive consumption. The lectures cover several important concepts of the physics of image formation and analysis, which require a basic level of mathematics. An emphasis will be given to highlighting common properties between diffraction and image data and how to take advantage of tools from both techniques during the final image processing projects.

Aim:

This course provides an introduction into electron microscopy techniques and applications in biology. Participants will obtain the background knowledge for critical reading of current literature and will be exposed to practical exercises in image processing.

Course Content:

1. History of the TEM / Design of a TEM - Lecture
2. Design of a TEM (cont'd) - Lecture
3. Design of a TEM (cont'd) - Lecture
4. Demonstration of a TEM - Demo
5. Math refresher / Electron waves - Lecture
6. Fourier transforms - Lecture
7. Intro to image processing software in SBGRID - Practical
8. Image alignment - Practical
9. Contrast formation and transfer - Lecture
10. Image recording and sampling - Student presentation
11. Applications in biology - Lecture
12. Preparation of biological samples - Demo
13. Low-dose cryo-EM - Student presentation
14. 2D crystallography - Student presentation
15. Overview of the single particle technique - Lecture
16. Review of theory - Lecture
17. Electron tomography (guest lecture) - Lecture
18. Physical limits to cryo-EM - Student presentation
19. Particle picking - Practical
20. Classification techniques - Student presentation
21. 3D reconstruction - Student presentation
22. Image processing project 1 - Practical
23. Resolution-limiting factors - Student presentation
24. Refinement and sources of artifacts - Student presentation
25. Image processing project 2 - Practical
26. A sampling of original literature – Discussion

Course Type:

Elective

Credits:

2

Assessment:

Participation 30%; Presentation, 30%; Practical Exercises 40%.

Text Book:

Transmission Electron Microscopy: A Textbook for Materials Science (4-vol set), by Williams and Carter (2009) Springer

Three-Dimensional Electron Microscopy of Macromolecular Assemblies, 2 edn, by J Frank (2006) Oxford University Press

Reference Book:

Transmission Electron Microscopy: Physics of Image Formation and Microanalysis, 4th edn, by L. Reimer (1997) Springer

Introduction to Fourier Optics, 3 edn, by J Goodman (2004) Roberts & Co.

Prior Knowledge:

Ideally combined with A410 Molecular Electron Tomography (Skoglund)

A410 Molecular Electron Tomography

Course Coordinator:

Ulf Skoglund

Description:

The course will show through theoretical and practical work how the 3D structure of a protein can be determined to about 2nm resolution directly in a buffer solution or in tissue. The students will get a direct hands-on experience of the processes involved in the practical and theoretical aspects of molecular electron tomography (MET). The students will be aware of how to carry out their own MET reconstruction and understand the limitations of the method and how to optimize its use.

Aim:

This course provides an overview of structure-function analysis of individual macromolecules.

Course Content:

1. Learning the computer
2. Learning the computer
3. Practical Aspect of sample preparation for cryo-TEM
4. Sample preparation for cryo-TEM
5. Sample preparation for cryo-TEM; data collection
6. 3D reconstruction
7. 3D reconstruction
8. 3D reconstruction
9. Generating simulation-data
10. 3D reconstruction from simulation-data
11. 3D reconstruction from simulation-data
12. Electron Microscopy: Sample Preparation

Course Type:

Elective

Credits:

2

Assessment:

Oral presentation of analyzed (cryo-)EM tomography article The major assessment is an oral presentation of a selected article in tomography. The students also have to pass the practical sessions in specimen preparations and data processing using computers

Text Book:

Basic papers will be used. There is no published book yet on low-dose cryo-electron tomography on normal sized proteins.

Reference Book:

Electron Tomography (Three-dimensional imaging with the transmission electron microscope) edited by Joachim Frank (1992) Plenum Press New York. One edition is from 1992.

B05 Cellular Neurobiology

Course Coordinator:

Tomoyuki Takahashi

Description:

In this course students learn about the cellular and molecular basis of neuronal functions, and how individual electrical signals are integrated into physiological functions. The course is a combination of student-led presentations on each of the key topics, and also student presentations of several classic papers, and a series of laboratory explorations of the topics covered in class.

Aim:

This course provides an overview of cellular neurophysiology and looks closely at the fundamental aspects of action potentials and synaptic signalling, in preparation for other advanced courses in neuroscience.

Course Content:

Theory Classes

Membrane potential (I)

Methods for recording electrical signals

Cell membrane compositions

Intracellular and extracellular ionic compositions

Membrane potential, polarization, depolarization, hyperpolarization

Membrane capacitance

Electrical properties of cell membrane

Nernst equation

Calculation: Equilibrium potentials of Na+ and K+, based on extracellular and intracellular ionic compositions.

Membrane potential (II)

Selective permeability of Na and K ions

Resting membrane potential described by Goldman-Hodgkin-Katz equation

Hodgkin-Huxley membrane model circuit

Active transport

Na-K ATPase

Action potential (I)

Voltage-clamp recording; principle and practice

Cable properties of axonal membrane

Molecular structure of voltage-gated Na channels

Relationship between single Na channel currents vs whole cell Na currents

Channel activation, channel deactivation vs channel inactivation

Na current-voltage relationship

Voltage dependence of Na channel conductance

Mechanism of channel inactivation: the ball-and-chain model

Action potential (II)

Voltage-gated K channels: molecular structure

Single K channel vs whole cell K currents

K current-voltage relationship

Voltage dependence of K channel conductance

Mechanism of action potential generation and repolarization

Refractory period

Calculation: Amount of Na influx in response to a single action potential, and its impact on intracellular Na concentration (assuming cell size).

Synaptic transmission (I)

Structural organization of synapses

Equilibrium potential for Ca ion.

Voltage-gated Ca channels: molecular structure and subtype classification

Ca current-voltage relationship and conductance

Non-linear relationship between Ca and transmitter release.

Synaptic transmission (II)

Roles of Ca channels and K channels in transmitter release

Quantal nature of transmitter release; from binomial to Poisson theorem

Synaptic transmission (III)

Exocytosis, endocytosis, vesicle recycling

Molecular mechanisms of transmitter release

Ca domain in the nerve terminal: how to estimate its size?

Synaptic vesicle recycling and reuse

Vesicular transmitter refilling mechanism

Synaptic transmission (IV)

Ligand-gated ion channels: molecular structure

Nicotinic acetylcholine receptor, AMPA receptor, NMDA receptor,

Glycine receptor, GABA(A) receptor

EPSP/EPSC, IPSP/IPSC; Equilibrium potentials: calculation

Regulatory mechanisms for intracellular Cl concentration

Sensory transduction mechanisms

G protein-coupled receptors

Second messengers and targets

Muscle spindle, stretch-activated channels

Auditory transduction, from sound to action potentials

Visual transduction, from light to action potentials

Olfactory transduction, from odor to action potentials

Synaptic integration & modulation

Patellar-tendon reflex

Reciprocal inhibition

Postsynaptic inhibition, presynaptic inhibition

Feedback and feedforward inhibition

Lateral inhibition

Retrograde inhibition

Autoreceptor

Short-term facilitation and depression

Long-term potentiation (LTP) and depression (LTD)

Long-lasting LTP (LLTP)

Role of NMDAR in LTP

Role of glia in LTP

Laboratory Sessions (Takahashi Unit)

Membrane Potential

Action Potential

Synaptic Transmission

Synaptic integration & modulation

Course Type:

Elective

Credits:

2

Assessment:

Student presentations on classic papers, class discussion, and a final report summarising what the student learned in the course.

Text Book:

Principles of Neural Science, 5 edn, Kandel, Schwartz, Messel, Siegelbaum and Hudspeth (2012) McGraw-Hill

Ion Channels of Excitable Membranes, 3 edn, Bertil Hille (2001) Sinauer

Neuroscience, 5 edn, by Dale Purves, George J. Augustine, David Fitzpatrick, William C. Hall, Anthony-Samuel LaMantia, and Leonard E. White (2012) Sinauer

Fundamental Neuroscience 3 edn, Larry Squire, (2008) Elsevier (Academic Press)

B08 Physics for Life Sciences

Course Coordinator:

Bernd Kuhn

Description:

Principles of physics of central relevance to modern biological analysis and instrumentation are introduced with an emphasis on application in practical research areas such as electrophysiology, optogenetics, electromagnetics, the interaction of light and matter, and brain recording, stimulation, and imaging.

Aim:

This basic course aims to introduce physical principles that are necessary in modern life sciences.

Course Content:

1. Introduction - Physics in Biology: How physics contributes to life sciences.
2. Nature of light
3. Nature of matter
4. Fundamentals on light and matter interaction
5. Fluorescence and its applications Part 1
6. Fluorescence and its applications Part 2 - Solvatochromism and Electrochromism
7. Biophotonics
8. Photosynthesis
9. The physics of optogenetics
10. Linear optics
11. Microscopy
12. Non-linear optics, lasers, two-photon microscopy, super resolution microscopy
13. The physics of DNA, lipid membranes, and proteins
14. Bioelectricity
15. Electronics for electrophysiology
16. Magnetic resonance

Course Type:

Elective

Credits:

2

Assessment:

Midterm presentation 25%, Final presentation 25%, participation + homework 25%, 30 minutes oral examination 1-2 weeks after the last lecture 25%

Text Book:

Atkins Physical Chemistry, by P. Atkins & J. de Paula (2006) Oxford University Press

Introduction to Biophotonics by P.N. Prasad, (2003) J. Wiley & Sons

Foundations of Cellular Neurophysiology by D. Johnston & S.M-S. Wu (1994) The MIT Press

B10 Analytical Mechanics

Course Coordinator:

Mahesh Bandi

Description:

Mastery of the concepts and techniques of analytical mechanics is essential to a deep understanding of physics. This course begins with basic principles and proceeds to the Newtonian equations of motion and laws of conservation. We use the Lagrange formalism to describe particle motion in multiple modes, before covering the equations of Euler and Hamilton, and canonical transformations. The calculus of variation is used to develop Maupertuis's principle and the Hamilton-Jacobi equations, providing a starting point for the consideration of waves in later courses. This course is taught from the unifying principles of symmetry and least action.

Aim:

Covers the fundamental theories of classical mechanics, and provides a firm grounding for later studies of fluid dynamics and quantum physics.

Course Content:

1. The Principle of Least Action

2. Equations of Motion: Galileo and Lagrange

3. Equations of Motion: Newton

4. Conservation Laws: Energy, Momentum, and Angular Momentum

5. Integration of Equations of Motion

6. Breakup, Collision, and Scattering of Particles

7. Harmonic Oscillations: Free, Forced, and Damped Oscillations, Resonance
8. Rigid Body Dynamics: Angular Velocity, Inertia Tensor, Angular Momentum
9. Equations of Motion for Rigid Body
10. Euler's Equations
11. Dynamics of Rigid Bodies in Contact
12. Hamilton's Equations
13. Maupertuis' Principle
14. Canonical Transformations and Liouville's Theorem
15. Hamilton-Jacobi Equation

Course Type:

Elective

Credits:

2

Assessment:

Homework Assignments, 20%. Midterm written tests, 2 x 25%; Final written test, 30%.

Text Book:

Mechanics, 4 edn, by Landau and Lifshitz (1976) Butterworth-Heinemann

Classical Mechanics, 3 edn, by Goldstein, Poole, and Safko (2001) Addison Wesley

Reference Book:

The Variational Principles of Mechanics, 4 edn, Cornelius Lancoz (1970) Dover

The Feynman Lectures on Physics including Feynman's Tips on Physics: The Definitive and Extended Edition, 2 edn, by RP Feynman with Robert B. Leighton et al., editors (2005) Addison Wesley

B11 Classical Electrodynamics

Course Coordinator:

Tsumoru Shintake

Description:

A graduate course in analytical mechanics, covering the essential equations and their applications, to prepare for later courses in electrodynamics and quantum physics. This course assumes undergraduate level knowledge of mechanics and a firm grasp of calculus and vector mathematics. An understanding of static electromagnetic fields is extended through Maxwell's equations to a discussion of dynamic vector fields and electromagnetic waves. Along the way, numerous physical and technical applications of these equations are used to illustrate the concepts, including dielectrics and conductors, wave guides, and microwave engineering. Special relativity is introduced with discussion of relativistic and non-relativistic motion and radiation, using linear accelerators and synchrotron radiation as illustrative applications.

Aim:

Covers the theory and application of classical electrodynamics and special relativity, and provides a firm grounding for later studies of quantum physics.

Course Content:

1. Charge and Gauss's Law
2. Current and Ampere's Law
3. Divergence and Rotation
4. Induction
5. Capacitance and Inductance
6. Maxwell's Equation 1
7. Maxwell's Equation 2
8. Vector and Scalar Potentials
9. Electromagnetic Waves
10. Energy, Dispersion

11. Impedance Concept
12. Reflection and Matching Condition
13. Relativistic Equation of Motion
14. Radiation from a Moving Charge
15. Synchrotron Radiation

Course Type:

Elective

Credits:

2

Assessment:

Midterm tests, 2 x 30%; Final written test, 40%.

Text Book:

Electrodynamics of Continuous Media, 2 edn, by Landau, Pitaevskii, Lifshitz (1984)

Reference Book:

Electricity and Magnetism (Berkeley Physics Course, Vol.2) 2 edn by Edward M. Purcell (1986)

Waves (Berkeley Physics Course, Vol.3) 2 edn by Frank S. Crawford (1968) Butterworth-Heinemann

The Classical Theory of Fields, 4 edn, by DL Landau (1980) Butterworth-Heinemann

Classical Electrodynamics, 3 edn, by JD Jackson (1998) Wiley

B12 Statistical Physics

Course Coordinator:

Nic Shannon

Description:

Matter can exist in many different phases. The aim of this course is to explain why, and how one phase can transform into another. Starting from the question “what is temperature?”, the ideas of entropy, free energy, and thermal equilibrium are introduced, first in the context of thermodynamics, and then as natural consequences of a statistical description of matter. From this starting point, a simple physical picture of phase transitions is developed, with emphasis on the unifying concept of broken symmetry. The course is designed to be accessible to students from a wide range of educational backgrounds. It will be assessed through weekly problem sets, and a final presentation on a modern example of the application of statistical physics ideas, chosen by the student.

Aim:

This course introduces the fundamental concepts and mathematical techniques of equilibrium statistical mechanics in the context of two simple questions: Why does matter exist in different phases ? And how does it change from one phase to another?

Course Content:

1. General overview of phase transitions - what are they, and where do they happen?
2. Introduction to the basic concepts of thermodynamics - temperature, entropy, thermodynamic variables and free energy - through the example of an ideal gas.
3. Introduction to the basic concepts and techniques of statistical mechanics - phase space, partition functions and free energies. How can we calculate the properties of an ideal gas from a statistical description of atoms?
4. Introduction to the idea of a phase transition. How does an non-ideal gas transform into a liquid?
5. The idea of an order parameter, distinction between continuous and first order phase transitions and critical end points. How do we determine whether a phase transition has taken place?
6. Magnetism as a paradigm for phase transitions in the solid state - the idea of a broken symmetry and the Landau theory of the Ising model.
7. Universality - why do phase transitions in fluids mimic those in magnets? An exploration of phase transitions in other universality classes, including superconductors and liquid crystals.
8. Alternative approaches to understanding phase transitions: Monte Carlo simulation and exact solutions.
9. How does one phase transform into another? Critical opalescence and critical fluctuations. The idea of a correlation function.
10. The modern theory of phase transitions - scaling and renormalization.
11. To be developed through student presentations: modern applications of statistical mechanics, with examples taken from life-sciences, sociology, and stock markets.

Course Type:

Elective

Credits:

2

Assessment:

Weekly problem sheets 75%. Final presentation 25%

Text Book:

K. Huang, “Introduction to Statistical Physics” 2nd Edition - (2009) Chapman & Hall

F. Mandl, “Statistical Physics”, 2nd Edition (1988) Wiley

M. Plischke and B. Bergersen, “Equilibrium Statistical Mechanics” 3rd edition (2006) World Scientific

Reference Book:

L. D. Landau and E. M. Lifshitz, “Statistical Physics” (1996) Butterworth-Heinemann

P. Chaikin and T. Lubensky, “Principles of Condensed Matter Physics” (2003) Cambridge University Press

B13 Theoretical and Applied Fluid Mechanics

Course Coordinator:

Pinaki Chakraborty

Description:

We will introduce basic concepts of flow of fluids. We will discuss conservation laws and constitutive equations. We will derive the Navier-Stokes equations, and study its exact and approximate solutions. Last, we will introduce the theory of hydrodynamic stability and then discuss turbulent flows. Throughout the course we will discuss a wide spectrum of flows from nature and engineering.

Aim:

To introduce basic concepts, equations, and methods of the mechanics of fluids.

Course Content:

1. Overview of fluid mechanics
2. Kinematics of flow
3. Review of Tensors and the Stress Tensor
4. Conservation Laws: Mass, Momentum, and Energy
5. Constitutive Equations: the Navier-Stokes Equations, Boundary Conditions.

6. Potential Flows
7. Vortex motion
8. Dimensional analysis and similarity
9. Exact solutions of viscous flows
10. Creeping Flows
11. Boundary Layers
12. Hydrodynamic Stability
13. Turbulent flows

Course Type:

Elective

Credits:

2

Text Book:

No textbook is set.

Reference Book:

Fluid Mechanics by L. D. Landau and E. M. Lifshitz, 2 edn (1987) Butterworth-Heinemann

Vectors, Tensors and the Basic Equations of Fluid Mechanics by Rutherford Aris (1990) Dover

General Continuum Mechanics by T. J. Chung (2007) Cambridge University Press

Fluid Dynamics for Physicists by T. E. Faber (1995) Cambridge University Press

An Introduction to Fluid Dynamics by G. Batchelor (2000) Cambridge

Scaling by G. I. Barenblatt (2003)

Fluid Mechanics by P. K. Kundu and I. M. Cohen, 5 edn (2011) Academic Press

Prior Knowledge:

Prerequisite is A104 Vector and Tensor Calculus

B14 Theoretical and Applied Solid Mechanics

Course Coordinator:

Gustavo Gioia

Description:

Students are introduced to the concepts of stress and strain, and discuss conservation laws and constitutive equations. We derive the Navier equations of linear elasticity, introduce the Airy stress-function method, and solve problems to illustrate the behavior of cracks, dislocations, and force-induced singularities in applications relating to materials science, structural engineering, geophysics and other disciplines.

Aim:

To introduce basic concepts, equations, and methods of the mechanics of solids, including solutions of representative problems in linear elasticity.

Course Content:

(1) Mathematical Preliminaries:

- Summation convention, Cartesian, spherical, and cylindrical coordinates.
- Vectors, tensors, linear operators, functionals.
- Eigenvalues and eigenvectors of second-order symmetric tensors, eigenvalues as extrema of the quadratic form.
- Fields, vector and tensor calculus.

(2) Stress, Strain, Energy, and Constitutive Relations:

- Cauchy stress tensor, traction, small strain tensor, compatibility.
- Strain energy, strain energy function, symmetries, elastic modulii.

(3) Elasticity and the Mechanics of Plastic Deformation:

- Navier equations, problems with spherical symmetry and problems with cylindrical symmetry (tunnels, cavities, centers of dilatation).
- Anti-plane shear. Plane stress, plane strain.
- The Airy stress-function method in polar and Cartesian coordinates.
- Superposition and Green's functions.
- Problems without a characteristic lengthscale.

- Flamant's problem, Cerruti's problem, Hertz's problem.
- Load-induced versus geometry-induced singularities (unbounded versus bounded energies).
- Problems with an axis of symmetry.
- Disclinations, dislocations, Burgers vector, energetics; relation to plastic deformation in crystalline solids.

(4) Fracture Mechanics:

- The Williams expansion, crack-tip fields and opening displacements via the Airy stress-function method (modes I, II) and via the Navier equations (mode III), crack-tip-field exponents as eigenvalues, stress intensity factors.
- Energy principles in fracture mechanics, load control and displacement control.
- Energy release rate and its relation to the stress intensity factors, specific fracture energy, size effect, stability. The Griffith crack and the Zener-Stroh crack. Anticracks.

(5) Possible Additional Topics (if time allows):

- Elasticity and variational calculus, nonconvex potentials, two-phase strain fields, frustration, microstructures.
- Stress waves in solids, P, S, and R waves, waveguides, dispersion relations, geophysical applications.
- Dislocation-based fracture mechanics, the Bilby-Cotterell-Swindon solution, small- and large-scale yielding, T-stress effects, crack-tip dislocation emission, the elastic enclave model.
- Deterministic versus statistical size effects in quasibrittle materials.
- Vlasov beam theory, coupled bending-torsional instabilities.
- Dynamic forms of instability, nonconservative forces, fluttering (Hopf bifurcation).

Course Type:

Elective

Credits:

2

Text Book:

No textbook is set. Students are expected to take good notes in class. The Professor will from time to time distribute essential readings, as needed.

Reference Book:

General Continuum Mechanics by T. J. Chung (2007) Cambridge University Press

Scaling by G. I. Barenblatt (2003)

Prior Knowledge:

Prerequisite is A104 Vector and Tensor Calculus

B15 Immunology

Course Coordinator:

Hiroki Ishikawa

Description:

In this course, students will learn basic principles of immunology including the cellular and molecular mechanism of innate and adaptive immunity. The course also provides the clinical importance of immunology in various diseases such as HIV/AIDS, autoimmunity and allergy. Then, students will learn how the immune response can be manipulated by vaccination to combat infectious diseases and cancer.

Aim:

This lecture series introduces the basic principles and current research in immunology.

Course Content:

1. Basic concepts in immunology
2. Innate immunity
3. Antigen recognition by B-cell and T-cell receptors
4. The generation of lymphocyte antigen receptors
5. Antigen presentation to T lymphocytes
6. Signaling through immune system receptors
7. The development and survival of lymphocytes
8. T cell-mediated immunity
9. The humoral immune response
10. Dynamics of adaptive immunity
11. The mucosal immune system
12. Failures of host defense mechanism
13. Allergy and Hypersensitivity
14. Autoimmunity and Transplantation

15. Manipulation of the immune response

Course Type:

Elective

Credits:

2

Assessment:

Report 50%; Final exam 50%

Reference Book:

Immunobiology 9th edition, by Kenneth Murphy (2016) Garland Science

B20 Introductory Evolutionary Developmental Biology

Course Coordinator:

Hiroshi Watanabe

Description:

This course will provide an introduction to Evolutionary Biology focusing on the developmental process of multicellular organisms for students with and without an undergraduate background in this field. Two major goals in this course will be to understand evolutionary changes in development and to learn modern creatures and technologies employed for addressing issues in evolutionary developmental biology. This course presents the basic principles and recent findings in evolutionary developmental biology.

Aim:

This course presents the basic principles and recent findings in evolutionary developmental biology.

Course Content:

1. Animal phylogeny I
2. Animal phylogeny II

3. Gene homology
4. Practice: Molecular Phylogeny
5. Gene expression
6. Signaling pathways I
7. Signaling pathways II
8. Research tools for EvoDevo I
9. Research tools for EvoDevo II
10. New Animal Models

Course Type:

Elective

Credits:

2

Assessment:

Midterm Reports 70% (2 x 35%), Presentation 30%

Text Book:

original papers will be supplied as required

Reference Book:

Animal Evolution Interrelationships of the Living Phyla, 3 Edn, by Nielsen (2011) Oxford University Press

Developmental Biology, 11 Edn, by Gilbert and Barresi (2016) Sinauer

The Evolution of Organ Systems, by Schmidt-Rhaesa (2007) Oxford University Press

Evolutionary Transitions to Multicellular Life Principles and mechanisms, by Ruiz-Trillo and Nedelcu (2015) Springer

Prior Knowledge: No prior knowledge assumed

B21 Biophysics of Cellular Membranes

Course Coordinator:

Akihiro Kusumi

Description: Students will learn several basic concepts of biophysics including thermal conformational fluctuation and thermal diffusion, and how cells might take advantage of these physical processes to enable their functions. As a biological paradigm, the cellular membrane system (and their functions), with a special attention paid to signal transduction in the plasma membrane, will be extensively covered. This is because the membranes are critically important for a variety of cellular processes, in the fields of cancer biology, immunology, neuroscience etc., and also because the membrane system provides us with an interesting and useful biological paradigm to learn how the life processes are made possible by thermal-physical processes. As a way of directly "seeing" the thermal, stochastic processes exhibited by receptors and downstream signaling molecules undergoing signaling in live cells, the methods of single-molecule imaging-tracking and manipulation will be discussed quite extensively. Through this course, students will better understand the interdisciplinary field of biology, chemistry, physics, and mathematical science.

Aims: This lecture series introduces the basic concepts and current research in cellular biophysics of biological membrane systems.

Course Content:

1. Introduction to Biophysics
2. Biological Membrane Structure and Molecular Dynamics
3. Signaling in the Plasma Membrane I
4. Single-molecule Imaging and Manipulation of Plasma Membrane Molecules
5. Interaction between the Plasma Membrane and the Cytoskeleton
6. Force Involved in Organizing Membrane Molecules
7. Domain Structures of the Plasma Membrane
8. Signaling in the Plasma Membrane Enabled by Its Meso-Scale Domain Organization
9. 3D-Organization of the Plasma Membrane: Endocytosis and Exocytosis
10. Membrane Deformation
11. Interaction between the Cytoplasmic Membranes and the Cytoskeleton
12. Tubulovesicular Network in Cells
13. Signaling in the Plasma Membrane II
14. Biological Meso-scale Mechanisms

Course Type:

Elective

Credits:

2

Assessment:

Report 50%; Final exam 50%

Text Book:

Mary Luckey, Membrane Structural Biology 2nd Ed. Cambridge University Press

Prior Knowledge:

Biology, chemistry, or physics at undergraduate levels

B22 Computational Methods

Course Coordinator:

Tom Froese

Description:

The course starts with basic programming using Python, with some notes on other computing frameworks. Students then get acquainted with data manipulation and visualization using “numpy” and “matplotlib.” After learning how to define one’s own function, students learn iterative methods for solving algebraic equations and dynamic simulation of differential equations. The course also covers basic concepts in stochastic sampling, distributed computing, and software management. Toward the end of the course, each student will pick a problem of one’s interest and apply any of the methods covered in the course to get hands-on knowledge about how they work or do not work.

Aim:

This course aims to provide students from non-computational backgrounds with the basic knowledge and practical skills for computational methods required today in almost all fields of science. Python is used as the standard programming language, but the concepts covered can be helpful also in using other computing tools for data analysis and simulation.

Course Content:

1. Introduction to Python
2. Vectors, matrices and other data types
3. Visualization
4. Functions and classes
5. Iterative computation
6. Ordinary differential equation
7. Partial differential equation
8. Optimization
9. Sampling methods
10. Distributed computing
11. Software management
12. Project presentation

For each week, there will be homework to get hands-on understanding of the methods presented.

Course Type:

Elective

Credits:

2

Assessment:

Homework: 75% (2 hours per week), Project 25%.

Text Book:

Valentin Haenel, Emmanuelle Gouillart, Gaël Varoquaux: Python Scientific Lecture Notes. (http://scipy-lectures.github.com/)

Reference Book:

Python Documentation. (https://docs.python.org/)

Prior Knowledge:

Prerequisite courses and assumed knowledge: Basic computer skill with Windows, MacOS, or Linux is assumed. Each student will bring in a laptop provided by the Graduate School. Knowledge of basic mathematics, such as the calculus of vectors and matrices and the concept of differential equations, is assumed, but pointers for self-study are given if necessary.

B23 Molecular Evolution

Course Coordinator:

Tom Bourguignon

Description:

Life sciences have been greatly influenced by the progress of DNA sequencing technologies. The field of Evolutionary Biology is no exception, and increasingly relies upon fast generation of DNA sequences, that are analysed using fast evolving bioinformatics tools. The aim of this course is to introduce the basic concepts of molecular evolution to students of all scientific backgrounds. We will explore some important questions in Biology, and through concrete examples, determine how molecular evolution theory help answering them. The students will also learn how to use a number of widely used bioinformatics tools.

Aim:

Understanding the theoretical concepts of molecular evolution and their application to solve biological questions.

Course Content:

1. DNA, RNA and protein
2. Replication and mutation
3. Building a genome
4. Gene
5. Selection
6. Drift and population genetics
7. Evolution of species
8. Using DNA to build phylogenies
9. Putting dates on trees
10. High throughput sequencing: the rise of genomics and transcriptomics
11. Working with genome-scale data: Annotation, gene orthology, RNAseq…

12. Genomics of symbiosis
13. Amplicon metagenomics and environmental DNA
14. Ancient DNA and protein

Course Type:

Elective

Credits:

2

Assessment:

1/4 participation, 1/4 presentation, 1/2 homework and essay.

Text Book:

An Introduction to Molecular Evolution and Phylogenetics, by Lindell Bromham (2015) Oxford University Press

Prior Knowledge:

Assumes general knowledge in biology

B24 Neural Dynamics of Movement

Course Coordinator:

Marylka Yoe Uusisaari

Description:

The course will start from the mechanisms of animal movement, including the evolutionary, ecological and energetic aspects; we will explore the anatomical and mechanical features of the body machinery (such as muscles, bones and tendons) before investigating the structure and dynamic function of the neuronal circuits driving and controlling movements. We will thus examine neuronal function at various levels, allowing the students to familiarize themselves with many fundamental concepts of neuroscience; the theoretical lectures will be complemented by practical exercises where the students will study movement in themselves and their peers in the motion capture laboratory environment as well as with more classical approaches.

Aim:

This course aims to provide an introductory-level overview of the structures and mechanisms underlying brain function in the context of generating and modulating physical movement of the body.

Course Content:

BLOCK 1 (4 weeks): The physical reality of movement

- Environments, evolution and fitness
- Movement styles - running, flying, swimming
- Mechanics of movement - forces, angles, timing
- Body mechanics - muscles, bones, tendons

BLOCK 2 (5 weeks): Movement generation

- Reflexes and drive in neuromuscular control
- Principles of neuronal circuit function
- Pattern generation in spinal systems
- Ascending brainstem pathways - reflex modulation
- Descending brainstem pathways - drive and modulation of locomotion

BLOCK 3 (4 weeks): Moving with purpose

- Motor cortex - commanding descending pathways
- Somatosensory cortex - monitoring movement
- Adjusting movements - sensory feedback, cerebellar systems
- Motor learning
- Linking motor behavior to cognitive function

Course Type:

Elective

Credits:

2

Assessment:

Participation and Discussion 40%; In-term exams 30%; Project work 30%

Text Book:

Animal Locomotion (English Edition) 2nd Edition by Andrew Biewener Sheila Patek ISBN-13: 978-0198743163

Reference Book:

Principles of Neural Science, by Kandel, Schwartz, Jessell, Siegelbaum, Hudspeth (2012) MIT Press

Handbook of Brain Microcircuits, by Shepherd & Grillner (2010) Oxford University Press

Prior Knowledge:

This is a basic level course, which will be adjusted according to the interests of enrolled students. No prior knowledge assumed, and suitable for out-of-field students.
However, the course B26 Introductory Neuroscience is required if you intend to continue with additional Neuroscience courses.

B26 Introduction to Neuroscience

Course Coordinator:

Izumi Fukunaga

Description:

This is a basic course targeted to those without neuroscience background, or those who need to refresh knowledge of key concepts to prepare for more advanced courses in Neuroscience.

This will serve as a pre-requisite for several Neuroscience courses. All neuroscience students need to pass this course before going on to other courses, unless they can demonstrate that they have already mastered the topics by passing the exam.

Assessment will be in the form of an exam at the end. This is not meant to be a stressful experience, but an opportunity for all students to demonstrate the understanding of the materials in their own words. In the exam, each lecturer will submit a short question based on the lecture content and the reading materials indicated in the course description. Each answer should be about 100 words long. Some questions may bridge lecture materials from two or more lectures. Students will be expected to answer all questions. A pass is 50%.

Students with prior knowledge but wishing to attend a part of the course will be allowed to audit.

Aim:

An introduction to neuroscience, from cellular to systems, and brief introduction to several areas of specialization available at OIST. This course is co-taught by neuroscience faculty on a rotating basis.

Course Content:

1 Course motivation

Krakauer et al, 2017; Pererira et al., 2020

Samuel Reiter

- Evolution of neural systems. Homology and convergence
- Choosing a model system to study: Krogh's principle
- Approaches to studying animal behavior and its neural basis
- Methods for tracking animal behavior

2 Cell biology basics

Ichiro Maruyama

- Fundamentals of cell biology in the context of neuroscience
- Brain ->nervous system -> neurons, cells -> constituents of cells: cell surface including sugars, cell membranes including lipids, organelles, nucleus, proteins, RNA and DNA.

3 Neurobiology concepts (building blocks - neurons, morphology)

Purves pg 1-10, Ch. 4

Gordon Arbuthnott

- Neurons are cells too; They just don't divide
- Cajal and the neuron doctrine
- Varieties shapes and connection types
- Modern methods to see them.
- They need support from glial cells
- They work together in dynamic teams
- The layout of the architecture is the next lecture

4 Organisation of the nervous system/neuroanatomy

Purves pg 13- 23; other neuroanatomy textbook

Izumi Fukunaga

- Peripheral, central, autonomic and enteric nervous systems
- Forebrain, midbrain, hindbrain
- Cranial nerves
- Cortex, subcortical regions, brainstem, Spinal cord
- Sulci and gyri, layers, Brodmann areas

- Special organs (eyes, ears etc.)

5 Bioelectricity

Purves Ch. 2, 3

Jeff Wickens

- Passive electrical properties of neurons
- Electrical current flow in neurons
- Electrochemical origin of membrane potential
- Voltage-dependent Ion channels
- Ionic basis of action potentials
- Action potential propagation in axons and dendrites

6 Synapses

Purves Ch. 5,6

Erik De Schutter

- electrical versus chemical synapses
- neurotransmission and the vesicle cycle
- neurotransmitter receptors: excitation and inhibition synaptic integration

7

Molecular Signaling within neurons

Purves Ch. 7

Marco Terenzio

- Introduction to receptor signaling in neurons
- Second messengers (cAMP, Ca2+, and IP3)
- kinases and phosphatases in neuronal signaling
- Neuronal transcriptional responses

8 Circuits

Purves pg. 11- 13

Yoe Uusisaari

- inhibitory vs excitatory neurons (GABA / glutamate)
- interneurons vs projection neurons

- scales of circuitry: local microcircuit, mesoscale circuit, systemic circuit
- convergence, divergence feed-forward, feedback, recurrent signaling

9 Learning and memory, Mechanisms

Purves Ch 23, 24, 30

Yoko Sugiyama

- Synaptic plasticity (for learning), short-term and long-term potentiation and depression
- Studies of synaptic plasticity using Aplysia, and the hippocampus in mammals

10 Learning and Memory, Mechanisms 2

Purves Ch8, Ch31

Kazumasa Tanaka

- different types of memory (e.g. explicit vs implicit, recent vs remote, etc.)
- hippocampal contribution to memory (studies in human, non-human animals, hypotheses)
- hippocampal physiology (synaptic plasticity, oscillation, place cells, etc.)

11 Learning and memory, Behavioural aspects

Gail Tripp

- Behavioural aspects of learning
- Pavlovian and instrumental learning
- Schedules of reinforcement

12 Evolution and Developmental Neurobiology

Purves Ch 22, 23, 25

Ichiro Masai

- Genetic program for regional patterning in the brain
- Neurogenesis
- Neuronal polarity
- Axon guidance
- Neuronal degeneration and regeneration

13 Methodology 101

Carter, Shieh

Bernd Kuhn

- Electrophysiology
- Optical imaging
- Interaction of light and tissue
- Indicators
- Microscopes
- Optical stimulation
- fMRI

14 Introduction to theoretical and computational neuroscience

Dayan/Abbott.

Erik De Schutter & Jun Tani

- General introduction and to molecular & cellular modelling
- Introduction to machine learning; perceptron, back propagation,

recurrent networks

15 Introduction to neural network modeling

Dayan/Abbott

Tomoki Fukai

- attractor network models including Hopfield-type associative memory and working memory circuits, etc.

Course Type:

Elective

Credits:

2

Assessment

Assessment will be in the form of an exam at the end. This is not meant to be a stressful experience, but an opportunity for all students to demonstrate the understanding of the materials in their own words. In the exam, each lecturer will submit a short question based on the lecture content and the reading materials indicated in the course description. Each answer should be about 100 words long. Some questions may bridge lecture materials from two or more lectures. Students will be expected to answer questions. A pass is 50%.

Those with neuroscience background who choose not to take this introductory course, but still wishing to take more advanced neuroscience courses, will still be required to pass the exam.

Text books and other suggested reading

(1) Carter, Shieh: Guide to Research Techniques in Neuroscience, 2nd edition

(2) Purves, Augustine, Fitzpatrick, Hall, Lamantia and White: Neuroscience, 5th edition

(3) Dayan and Abbott: Computational Neuroscience

(4) Hill: Ion Channels of Excitable Membranes

(5) Krakauer et al., (2017) Neuroscience Needs Behavior: Correcting a Reductionist Bias. Neuron 93: 480 – 490.

(6) Pereira et al., (2020) Quantifying behavior to understand the brain. Nature Neuroscience 23: 1537-1549.

Prior Knowledge: no prerequisites

B27 Molecular Biology of the Cell

Course Coordinator:

Keiko Kono

Description:

We will read through the textbook “Molecular Biology of the Cell”, one chapter per class.

Students will work through the Problems workbook on their own as needed, but Professor Kono offers Office hours every Friday for student help.

Aim:

This course aims to revisit the basic knowledge of molecular and cell biology at the undergraduate level. Target students are 1) those who did not major in molecular or cell biology, or 2) molecular/cell biology student who wants to review the basic knowledge of the field.

Course Content:

1. Cells and Genomes

2. Cell Chemistry and Bioenergetics
3. Proteins
4. DNA, Chromosomes, and Genomes
5. DNA Replication, Repair, and Recombination
6. How Cells Read the Genome: From DNA to Protein
7. Control of Gene Expression
8. Examination 1
9. Analyzing Cells, Molecules, and Systems
10. Visualizing Cells
11. Membrane Structure
12. Membrane Transport of Small Molecules and the Electrical Properties of Membranes
13. Intracellular Compartments and Protein Sorting
14. Intracellular Membrane Traffic
15. Energy Conversion: Mitochondria and Chloroplasts
16. Cell Signaling
17. The Cytoskeleton
18. The Cell Cycle
19. Cell Death
20. Examination 2
21. Cell Junctions and the Extracellular Matrix
22. Cancer
23. Development of Multicellular Organisms
24. Stem Cells and Tissue Renewal
25. Pathogens and Infection
26. The Innate and Adaptive Immune Systems
27. Examination 3

Course Type:

Elective

Credits:

2

Assessment:

Three small examinations during the term, weighted 25%, 25%, and 50%.

Text Book:

Molecular Biology of the Cell, 6th Edition, by Bruce Alberts et al.

Reference Book:

The Problems Book for Molecular Biology of the Cell 6th Edition, by Tim Hunt and John Wilson

Prior Knowledge:

The course is very basic. Non-biology students are welcome.

B28 Elementary Differential Equations and Boundary Value Problems

Course Coordinator:

Daniel Spector

Description:

The main reason for solving many differential equations is to try and learn something about an underlying physical process that the equation is believed to model. It is basic to the importance of differential equations that even the simplest equations correspond to useful physical models, for example, exponential growth and decay, spring-mass systems, or electrical circuits. Gaining an understanding of a complex natural process is usually accomplished by combining or building upon simpler and more basic models. Thus, a thorough knowledge of these models, the equations that describe them, and their solutions is the first and indispensable step toward the solution of more complex and realistic problems.

The successful student will firstly be capable of computing the solutions of various ordinary and partial differential equations that are useful in modeling natural phenomena. This proficiency is essential toward the greater aim, which is to help the student to understand something about mathematics and its role in science and modeling.

Target Students

Students with prior knowledge of calculus who want to advance their skills and apply this to solution of real-world problems.

Aim:

In this course we will study various differential equations as models of natural phenomena. For these equations we will demonstrate known techniques to obtain solutions. Through extensive homework exercises the student will master these techniques. This proficiency of calculation is essential for the student to understand the role of mathematics in science and modeling.

Course Content:

Boyce and DiPrima's "Elementary Differential Equations and Boundary Value Problems" Chapters 1-5 and 10

First order differential equations

Second order linear equations

Higher order linear equations

Series solutions of second order linear equations

Course Type:

Elective

Credits:

2

Assessment:

Homework/Worksheets: 70% (Approximately One Homework/Worksheet per class, ~2 hours per assignment) Exams: 30%

Text Book:

Boyce and DiPrima's "Elementary Differential Equations and Boundary Value Problems" ISBN: 978-1-119-38164-8

Reference Book:

Stein and Shakarchi's "Fourier Analysis: An Introduction"

Coddington and Levinson's "Theory of Ordinary Differential Equations"

Prior Knowledge:

At least three semesters of university calculus.

B29 Linear Algebra

Course Coordinator:

Liron Speyer

Description:

We will cover the basics of linear algebra, including proofs. This will start from the perspective of vector spaces over arbitrary fields, quickly specialising to real and complex vector spaces. We will study linear maps between vector spaces, how these can be realised as matrices, and how this can be applied to solving systems of linear equations.

Aim:

A basic math course for physics and/or engineering students, and also of interest to neuroscientists and others who need linear and matrix algebra in their research. Not intended for those with a solid mathematics degree.

Course Content:

Fields, vector spaces, and bases.

Matrix operations and solving systems of linear equations.

Row reduction and determinants.

Change of coordinates.

Eigenvalues, eigenvectors, diagonalisation.

Gram-Schmidt orthonormalisation.

Course Type:

Elective (Alternating years)

Credits:

2

Assessment:

Homework 100% – approx. 3 hours per week

Text Book:

Linear Algebra Done Wrong – Sergei Treil

Prior Knowledge:

Familiarity with real and complex numbers will be assumed. Ideally, students will have had some previous exposure to mathematical proofs, though this is not strictly required.

B30 Surface Sciences

Course Coordinator:

Yabing Qi

Description:

Surface science is a discipline devoted to elucidating fundamental properties of physics and chemistry occurring at surfaces and interfaces. Surface science contributes to many areas of science and technology, for example, physical chemistry, electronic devices, catalysis, semiconductor processing, new materials development, biomaterials, biotechnology and biomedicine, nanotechnology, and so on. This course is intended as an introduction to surface science basic concepts and instrumentation for graduate students. The objectives are twofold: (i) provide students with comprehensive lectures of basic concepts and operation principles of major analytical techniques in surface science and (ii) discussion of the applications of these concepts and instruments in various research fields.

Aim:

After taking this course, students will be able to understand the basic concepts, operation principles, and instrumentation of major analytical techniques in surface science, such as scanning tunneling microscopy (STM), atomic force microscopy (AFM), X-ray photoelectron spectroscopy (XPS), ultraviolet photoemission spectroscopy (UPS), etc. Target: Graduate students who wish to get a general knowledge of surface science concepts and techniques.

Course Content:

The following topics will be covered via lectures and projects: the basic concepts, operation principles, instrumentation and applications of scanning tunneling microscopy (STM), atomic force microscopy (AFM), X-ray photoelectron spectroscopy (XPS), ultraviolet photoemission spectroscopy (UPS), Inverse Photoemission Spectroscopy (IPES), etc.

Course Type:

Elective

Credits:

Assessment:

Homework assignments 50% (2 hours per week), 2 projects x 25% (8 hours / project).

Text Book:

Modern Techniques of Surface Science, 3 edn, D. Phil Woodruff (2016) Cambridge University Press

Concepts in Surface Physics, 2 edn, M.-C. Desjonquères and D. Spanjaard (1998) Springer-Verlag

Surface Science – An Introduction, K. Oura, V.G. Lifshits, A.A. Saranin, A.V. Zotov, M. Katayama (2003) Springer-Verlag

Reference Book:

Introduction to Scanning Tunneling Microscopy, C.J. Chen (1993) Oxford University Press

Photoelectron Spectroscopy – Principles and Applications, 3 edn, S. Hüfner (2003) Springer-Verlag

Prior Knowledge:

General knowledge in physics and chemistry

B31 Statistical Tests

Course Coordinator:

Tomoki Fukai

Description:

In this course, I will explain the basic methodology for hypothesis testing. Statistical analyses are required in many experimental and simulation studies. I will deliver lectures and exercises on the basics of probability theories and statistical methods including sample means, sample variances, p-values, t-test, u-test, Welch test, confidence intervals, covariance, ANOVA, multivariate analyses, correlations, information theory, mutual information, experimental design, and so on. After the course work, the students will acquire basic knowledge of hypothesis testing.

This course corresponds to the first half of the previous course "B07 Statistical Methods".

Aim:

This is a basic course. Those students who have not learned the basics of statistical methods and will conduct experimental studies or numerical simulations in the future are encouraged to take the course.

Course Content:

Every week, a lecture on each topic is followed by an exercise with Python language.

1. Introduction

History and basic concepts of hypothesis testing are explained. The fundamentals of probability distributions are also given.

2. Sampling and Central Limit Theory

The central limit theory is the core of various hypothesis testing methods. Low of large numbers and the theory is explained in the context of sampling from a population. I will also explain the degrees of freedom in data sampling.

3. T-test, U-test, Welch test

Comparison of means between two groups is frequently required in statistical assessment of measured data. Depending on the properties of data, however, different methods should be adopted. These methods are explained together with the basic notions of statistical significance and p-values.

4.Confidence Intervals

Now, the mere use of p-values is not encouraged by experts. First, I will explain why the use of p-values is not sufficient for statistical assessment. Then, I will show how statistical differences can be more reliably assessed within the hypothesis-testing framework by using the confidence intervals of the means and proportions.

5. ANOVA, Effect Size

Statistical comparison between multiple groups is frequently required in a realistic situation. I will explain how such a comparison can be done by comparing the within-class variances and the between-class variances. Various corrections required for multiple comparisons are also explained together with the criteria for statistical differences.

6. Correlation Analysis

Correlation analysis is a standard method for analyzing the statistical relationship between statistical variables. After explaining the meaning of statistical independence, I will explain the correlation analysis of continuous and discrete variables together with their limitations.

7. Information Theory

Information theory is a concept that was not discovered in ancient Greek. In particular, mutual information is often used for quantifying the relationship between two statistical variables. A virtue of mutual information is that unlike correlations mutual information is applicable to variables showing a nonlinear mutual relationship. I will explain the basics of information theory.

Course Type:

Elective

Credits:

1

Assessment:

weekly homework exercises and coding (75%), in-term test(25%)

Prior Knowledge:

Students are expected to have basic knowledge of elementary mathematics such as differentiation, integration, and elementary linear algebra. However, whenever necessary, mathematical details will be explained.

Students will need to write some code in Python.

B32 Statistical Modeling

Course Coordinator:

Tomoki Fukai

Description:

Modern technologies in experimental sciences and computational sciences generate a large amount of high-dimensional data. In contrast to classical hypothesis testing, in modern statistical methods data are used to construct a statistical model that generated the dataset. Such a model not only describes the statistical properties of the past observations but also enables the prediction of future observations. The course is designed for students who wish to learn the mathematical methods to analyze high-dimensional data for active inference.

This course is based on the second half of the previous course "B07 Statistical Methods".

By completing this course, students will receive one credit.

This course can be taken immediately after the course B31 Statistical Testing, or as a stand-alone course.

Aim:

This course provides an introduction to machine learning. Students are required to have some knowledge and skills in mathematics. However, the course is not intended for pure theorists. Students with a computational background will best fit the materials of the course. However, students with an experimental background are also highly welcome if they have strong interests in modern data analysis.

Course Content:

1. Introduction

The following points are explained.

Hypothesis testing versus statistical modeling (or machine learning)

Needs and difficulties of high-dimensional data analysis

A true model? Does it exist or not?

2. Regression analysis and maximum likelihood

Regression is an entry to statistical modeling and is yet a practically important topic. Some representative methods such as linear regression will be explained together with the Maximum likelihood Estimation. Logistic regression and Receiver operation curve (ROC) are also discussed.

3. Model selection

In statistical modeling, the same data can be fitted with multiple models having different levels of complexity. However, a complex model may induce an overfitting of data. Model selection enables us a systematic comparison between the different models. Akaike information criteria will be explained in detail.

4. Dimensional reduction

When high-dimensional data are given, we may analyze the structure of the distribution in a low-dimensional projection space. Principal component analysis (PCA) provides a basic yet very useful method for dimensional reduction of datasets. As a related topics, singular value decomposition (SVD) will be also discussed.

5. Categorization and decision making

Categorization or classification of data points is important in a wide range of real-world decision-making problems. Several methods for categorization including Linear discriminant analysis (LDA) are introduced. I will also explain a widely-used framework of Generalized linear model (GLM).

6. Bayesian approach

In contrast to the maximum likelihood estimation of a true model, Bayesian statistical modeling assumes that observations result from a mixture of multiple statistical models. I will explain the basic concepts of Bayesian statistical modeling using simple examples.

7. Clustering

Clustering is required in various feature-detection problems in data science, and several methods are known in machine learning. Here, we first study one of the simplest methods, k-means clustering. Bayesian approaches to clustering problems will be also discussed. Such topics will include Variational Bayes clustering if time allows.

Course Type:

Elective

Credits:

1

Assessment:

Weekly exercises and homework (75%), in-term examination (25%).

Text Book:

Christopher M. Bishop, "Pattern Recognition and Machine Learning", Springer Science, 2006.

Prior Knowledge:

Basic knowledge and skills in linear algebra (matrix, eigenvalues, eigenvectors, etc.), calculus (differentiation and integration of functions), and probability theories (Gaussian and some other distributions) are required. Skills in Python programming are also required for exercises.

B33 Organic Photonics and Electronics

Course Coordinator:

Ryota Kabe

Description:

This course covers the essential knowledge and technology of organic optoelectronics. Since the organic optoelectronics is an interdisciplinary research area, we need to understand organic molecular design and synthesis, purification, basic photophysics, device design and fabrications, and device physics. This course introduces the basics of all of these topics.

Aim:

Students will be able to understand the basic knowledge of organic photonics and electronics together with experimental skills. Target Students: Students interested in Chemistry, Materials Sciences, and Optoelectronics

Course Content:

1. Molecular design and organic synthesis
2. Organic synthesis and purification
3. Basics of photochemistry
4. Photophysical analysis 1 (Absorption and emission)
5. Photophysical analysis 2 (Kinetics)
6. Photophysical analysis 3 (Delayed fluorescence)
7. Photophysical analysis 4 (Environmental effects)
8. Basics of organic electronics
9. Device fabrications
10. Organic light-emitting diodes
11. Organic transistors
12. Organic solar cell
13. Organic laser

Course Type:

Elective

Credits:

2

Assessment:

Performance on experiments 50%, Experiment reports 50%

Prior Knowledge:

undergraduate level chemistry knowledge

B34 Coral Reef Ecology and Biology

Course Coordinator:

Timothy Ravasi

Description:

Among the most spectacular of all ecosystems, coral reefs form in the world's tropical oceans through the action of animals and plants. They are the largest and most complex biological structures on earth. Although they cover less than one percent of the earth's surface, they are reservoirs for much of the ocean's biodiversity, housing some of nature's most intricate ecological secrets and treasures. Coral reefs are also the most productive ecosystems in the sea and provide significant ecological goods and services, estimated at about $375 billion annually with more recent estimates topping 9 trillion dollars in 2019.

Their physical structures protect thousands of miles of coastline from the fury of tropical storms, tsunamis, and many low lying islands threatened by rising seas. The intricate adaptations for survival that have evolved over an immense span of time make reefs vulnerable to human activities. For example, excess nutrients support algal overgrowth, while over fishing alters the food web. The extent to which reefs in remote locations are now showing signs of stress, especially bleaching and disease, points to the critical role that coral reefs play as indicators of declining ocean health. This course will be an introduction to tropical coral reefs and the organisms and processes responsible for their formation. We will begin with an overview of reefs and their tropical marine environment. The course will then move into the evolution, systematic, and physiology, ecology and symbiosis of reef building corals. These subjects will set the stage for learning about coral reef fish communities structure and ecological dynamics. The course will close by taking a critical look at natural and human disturbances to reefs with an emphasis on current models of management and conservation. This will allow us to examine cutting-edge questions in coral reef biology and conservation.

Target Students

Students with background in general biology or marine science who wish to become tropical marine biologists specializing in coral reefs and coral reef fish.

Aim:

Student Learning Outcomes

1. Understand the basic characteristics of tropical waters

2. Understand the major characteristics of the key animals and plants on reefs

3. Recognize key processes on shallow and deep reefs

4. Appreciate variability among reefs, including those of the Okinawa

5. Consider the threats to coral reefs, and how they might be conserved

6. Understand how we conduct marine research, and how to read and interpret research papers

Course Content:

Introduction and course assignments

Reef invertebrates

Producers

Fish 1

Fish 2

Reef formation and evolution

Reef zonation

Grazers and grazing

Calcification and bioerosion

Reef resilience

Reproduction of reef species

Nursery habitats

Reef food webs

Biodiversity and biogeography

Survey methods (practical lectures via snorkeling)

The reefs of Japan

Threats to reefs

Reef conservation

Marine reserve design practical

Course Type:

Elective

Credits:

2

Assessment:

25% literature review 50% final exam 25% field trip and data analysis

Text Book:

Goldberg, W.M. The Biology of Reefs and Reef Organisms

Sheppard C.R.C, Davy, S.K., and Pilling, G.M. The Biology of Coral Reefs

Prior Knowledge:

Students need to have basic knowledge of general biology and zoology. Also, students must be able to swim and snorkel for the field trip component of the course.

B35 Genetics and Modern Genetic Technologies

Course Coordinator:

Tomomi Kiyomitsu

Description:

Genetics is the study of biologically inherited traits. Thus, genetics is related to all living organisms and more or less to all life science fields. In addition, modern genetic technologies not only have a strong impact on basic research, but on applied research as well, such as medicine and agriculture. This course introduces the key concepts of genetics and modern genetic technologies. In parallel to the lectures, students will see or experience CRISPR/Cas9-based genome editing using cultured human cells. Lecturers from outside of OIST may also be invited. The major goal of this course is to learn the key concepts of genetics and modern genetic technologies in order to utilize them and deal with their associated problems.

Aim:

Students who complete this course will understand the key concepts of genetics and the advantages of modern genetic technologies. In addition, through the exercise of genome editing using cultured human cells, students can realize the power, simplicity of use, and potential risks of genome editing technologies.

Target Students

1. Students who majored in biology or life science, and want to review the key concepts of genetics and learn modern genetic technologies.
2. Students who did not major in biology or life science, but are interested in genetics and its associated technologies.

Course Content:

1. Mendel’s principles of heredity and extensions to Mendel’s laws
2. The chromosome theory of inheritance
3. Linkage, recombination, and the mapping of genes on chromosomes
4. DNA structure, replication, and recombination
5. Anatomy and function of a gene: Dissection through mutation
6. Gene expression and analysis of genetic information
7. Chromosomal rearrangements and changes in chromosome number
8. Bacterial genetics and organellar inheritance
9. Gene regulation in prokaryotes and eukaryotes
10. Manipulating the genomes of eukaryotes
11. The genetic analysis of development and cancer
12. Variation and selection in populations
13. The genetics of complex traits
14. Discussion: Future improvements and ethical issues of genetic technologies
15. Exercise: Genome editing of cultured human cells

Course Type:

Elective

Credits:

2

Assessment:

Participation 20%, Examination 40%, and Presentation 40%

Text Book:

Genetics, From Genes to Genomes, Sixth edition, by Hartwell et al (2018), McGraHill Education

Reference Book:

Essential Genetics and Genomics, Seventh edition, by Daniel L. Hartl (2020), Jones & Bartlett learning.

Prior Knowledge:

This course no prerequisite courses.

Suggested to take this course alongside/after B27 Molecular Biology of the Cell

IND Independent Study

Description:

The course Independent Study will foster the development of independent study and research skills such as reading and critiquing the scientific literature, formulating scientific questions, and integrating knowledge into a coherent synthesis. Students will undertake a self-directed program of reading and synthesis of ideas. This course option must be conducted under the guidance of a faculty member acquainted with such work, and will follow common guidelines to ensure academic standards are maintained. Students should, in consultation with the faculty member, prepare a plan of the study, carry out the appropriate reading, and then describe the results of their study in a substantial report or essay. This course may be taken in any one term, and should be completed within the period of that term. The due date for all work, including online course completion, will be at the end of the current term.

The source material for Independent Study is now expanded to include online courses from a variety of educational sources, including Udacity, edX, and Coursera, subject to those courses being approved as relevant to the student's study and of sufficient educational merit. Seek approval before enrolling if credit is required. Total of external course credits permitted (online courses and international workshops) must be less than 50% of degree requirements. Your online course proposal must be approved by GS before you enroll in the online course, and the course fee can only be reimbursed if you purchase AFTER approval. Please contact Academic Affairs for assistance with online course purchase after we tell you that the course has been approved.

Student and tutor should agree on the extent of supervision provided, such as timing and format of face-to-face meetings, progress checks, and so on, especially for online courses. This should be detailed in the proposal, and the student should commit to this undertaking.

Aim:

The aim of this course is to provide an opportunity for independent learning on a topic that a particular student may wish to study individually, with appropriate guidance. Online courses allow formal structured tuition in areas not covered by the existing OIST course offerings.

Course Content: Tutorial style under supervision of an OIST faculty member.
As each topic will be a unique project with its own requirements, there is no fixed schedule.

The proposal for independent study should outline the material to be covered, and describe assessment items and tasks. Material that is delivered by set readings, exercises, and discussions at OIST are regarded as 'taught components', and must be assessed by some form of written assessment. Externally-provided material (such as online courses) may be included as all or part of the independent study content, and such material should not be assessed by the tutor, even where the tutor provides support and discussion.

Grades for this course are only Pass or Fail. If you enroll (after the proposal is approved, enrolment is automatic), you must complete or a Fail grade will be awarded. If not approved, you will be notified.

After completion, a student may be asked to provide a brief report on online course material, conditions, support, etc., to the Graduate School to assist in quality control.

Course Type:

Elective

Credits:

1

Assessment:

Written assessment of some form, or certificate of completion of online course, are required. Graded as Pass/Fail.

SPT Special Topics

Description:

The course Special Topics will provide an opportunity for students to study topics concerning recent scientific breakthroughs, cutting edge research of topical interest, novel, state of the art technologies, and techniques not otherwise available, with leading international experts in those topics or technologies.

This course option must be conducted in collaboration with a faculty member to provide internal academic oversight and guidance, and will follow common guidelines to ensure the required academic standards are maintained.

Each Special Topics course will require the approval of the Dean before being offered.

Students will be required to obtain the approval of the Academic Mentor or Thesis Supervisor before taking the course, and complete a defined piece of work as part of the course.

Aim:

The aim of the Special Topics category is to permit students to benefit from courses that are not usually available at OIST but that may be offered from time to time, for example by visiting part-time faculty, OIST scientific staff, or external professors.

Course Content:

Tutorial style under supervision of a faculty member.
As each topic will be a unique project with its own requirements, there is no fixed schedule.

A Special Topic will normally comprise a minimum of 15 hours class time.

Course Type:

Elective

Credits:

1

Assessment:

Written Project 100%

Mandatory Courses for AY2020/2021

ROT Laboratory Rotations

Description:

1. Prepare a written summary of the aims of the rotation. Students will study original publications and discuss with the Professor in charge of the research unit to prepare the aims. The summary should be no more than one page including references and illustrations. The proposal should be submitted to the graduate school as a PDF file via Sakai. Due date 30 days after first day of term.
2. Undertake the activities in the research unit to fulfill the aims of the rotation. The activities should be completed during the term of the rotation.
3. Participate in research unit meetings and seminars during the rotation. The student is expected to attend and as appropriate, ask questions, and join discussions.
4. Present the results of the rotation activity as an oral presentation to the laboratory members. One of the three rotations will be presented as an oral presentation to the entire class as a part of Professional Development.
5. Submit a written report on the rotation. It is understood that results cannot be expected in so short a time, but the background, including a short literature review, methods used, and activity carried out in the research unit should be described using the scientific language of the field. The report is due 14 days after the end of term. The Professor of the research unit will grade the report.
6. Each student will do a minimum of three laboratory rotations, one per term.

Selection of Rotations

All students will undertake at least three rotations. Assignment of rotations is made by the Graduate School, following information provided by the student in the pre-enrollment survey and from discussions during interview. Final approval of the selection of rotations will be given by the Dean, taking into account the availability of supervision and the overall program of the student. At least one of the rotations shall be outside the specific field of the student’s studies at OIST.

Aim:

To be able to discuss the scientific questions addressed in the research unit using the appropriate scientific language of the field, and to be aware of and able to explain the methods used in the research unit. The experience gained in these lab rotations will guide the student in their later choice of thesis laboratory.

Course Type: Mandatory

Credit: 3

Assessment:

Based on written report, participation in the laboratory, and oral presentation. The supervisor (Professor of the Unit) will report to the Dean on the student's attendance and participation in the laboratory meetings.

PRO Thesis Proposal

Description:

Students work in the laboratory of the Professor under whom they wish to conduct their thesis research. They undertake and write up preliminary research work, complete an in-depth literature review and prepare a research plan. The preliminary research work should include methods the students will use in their thesis research. The literature review should be in the area of their thesis topic and be of publishable quality. The research plan should comprise a projected plan of experiments to answer a specific question(s) and place the expected outcomes against the current state of knowledge, and should take into account the resources and techniques available at OIST. The research data generated in this proposal may be included in the subsequent doctoral thesis, if appropriate.

Aim:

Students prepare a proposal for the research they wish to pursue toward the submission of an independent, novel doctoral thesis.

Course Type: Mandatory

Credit: 3

Assessment:

Dean and Thesis Committee Evaluation

PCD1 Professional and Career Development I

Description:

This course aims to develop knowledge and skills important for leadership in scientific research and education. The three main components of the course are (1) weekly seminars covering basic principles of research conduct and ethics, scientific communication, and aspects of science in society, (2) a cross-disciplinary group project, and (3) practical experience to develop presentation and teaching skills.

Seminars

Seminars are held every Friday afternoon throughout the year. Seminars last 1 hour. It is imperative that you not only attend the seminars but that you also engage by participating in discussion and asking questions. You may be assigned specific responsibilities to facilitate discussion. In order to participate in discussion well, you'll need to prepare. This means more than simply reading the required articles. You'll need to reflect on them as well. You will be informed how to obtain the required articles one week ahead of the seminar they will be used in.

Group Project

The group project component aims to develop skills required for effective teamwork, including leadership, project management, cooperation and creative interaction, cross-disciplinary communication, and coordination of group activity. Group project work is timetabled on Friday afternoons for two hours every second week, alternating with presentation and teaching skills training. Timing of project activity is flexible and different times may be decided by the group. The project component will require involvement in a student led group project. Projects will not be directly supervised by a faculty member, but there will be opportunities for consultation where certain expertise is required. The nature of possible projects will be explained in class but they may include development of new research tools and applications, inventions to solve problems, field studies, or creation of resources for research and learning. There will be a self-assessment requirement by group members to recognize the contributions of different members, and an overall grade based on a final presentation. A prize will be awarded for the best project.

Presentation and Teaching Skills

The presentation skill component comprises a set of opportunities for students to gain experience in giving presentations to various groups and teaching at different levels. It is timetabled on Friday afternoons for two hours every second week, alternating with group project activity, but may be arranged flexibly. Students develop skills by a range of different assignments including: acting as teaching assistants; assisting with visiting student programs; contributing to outreach activities; presenting and participating in journal clubs; and giving a presentation based on research rotations. There will be a self-assessment requirement including a report documenting activities and evaluation of the research presentation.

Aim:

The aim of this course is to provide information essential to beginning one's career as a professional scientist, and to develop skills fundamental to modern scientific practice.

Course Content:

Term 1 Module: Research conduct and ethics

- laboratory procedures, conduct and safety
- record keeping and data management
- sharing and confidentiality
- authorship
- plagiarism
- peer review
- conflicts of interest
- research misconduct

- research with animals
- research with human subjects

Term 2 Module: Scientific communication

- scientific writing
- poster presentations
- scientific talks
- communicating science to the non-specialist
- teaching science
- grant applications

Term 3 Module: Life in science and science in society

- science and the law
- intellectual property and patents
- working in science
- reputation/visibility/personal profile
- funding of science
- research and social responsibility
- leadership in research and education
- This course continues in the 2nd year. Students in second year are expected to attend seminars presented by guest speakers. Students in second year may also participate in additional specific training if there is a need, such as further developing presentation and writing skills.

Course Type: Mandatory

Credit: 2

Assessment: Attendance and participation

PCD2 Professional and Career Development II

Description:

This course will comprise a series of seminars and workshops designed to prepare OIST graduates to function effectively and responsibly in their scientific career. Beyond the initial focus of research, a responsible scientist should be able to communicate their research to the informed public, to make the most effective use of the public and private funds entrusted to them, and to understand the place of their science in its social and ethical context. Communication, media, and presentation techniques will be developed beyond the level of Professional Development I, including the tools to present and manage one’s profile online and in person. Ethical considerations of life as a scientist will be addressed by discussion, debate and case studies. Invited experts from industry, science, patent and contract law, funding bodies, and so on will share their experience in generating and securing funding, typical intellectual property and industrial cooperation concerns, the business of running a research laboratory, and working in industry. Students will work in small groups or individually to complete relevant exercises to develop the skills to manage people and money. Students will be required to attend such seminars and workshops throughout their thesis research period.

Aim:

This course develops further the many competencies and values that underpin a successful career as a professional scientist.

Course Content:

A recurring series of seminars and workshops that extends PCD1 to more appropriate topics for research management and career development.

Course Type: Mandatory

Credit: 2

Assessment:

Participation in and contribution to the structured activities and exercises.