MASTER DEGREE COURSES OFFERED IN ENGLISH IN WINTER SEMESTER 2020-21

- **0100018 Wave propagation in periodic structures**
  Instructor: Dr. Ruming Zhang
  Weekly hours: 4+2

  This lecture introduces theoretical analysis and numerical methods to simulate wave propagation in periodic structures. This is an interesting topic in both mathematics and other areas, such as nano-technology. After this lecture, students will be able to apply tools to study well-posedness of quasi-periodic problems, i.e., integral equation methods and variational methods. They will also have basic knowledge of the Floquet-Bloch transform, which is applied to treat non-periodic waves propagating problems in periodic structures. They can simulate wave propagation phenomenon in periodic waveguides via integral equation methods and finite element methods. The content includes quasi-periodic scattering problems, wave propagating in open and closed waveguides, numerical methods to simulate scattering problems in periodic waveguides.

  Prerequisites: functional analysis, partial differential equation, numerical analysis
  The teaching will be online
  The time for lectures and problem classes are not available

- **0100024 Structural Graph Theory**
  Instructor: Dr. Richard Snyder
  Weekly hours: 3+1

  The purpose of this course is to provide an introduction to some of the central results and methods of structural graph theory. Our main point of emphasis will be on graph minor theory and the concepts devised in Robertson and Seymour's intricate proof of the Graph Minor Theorem: in every infinite set of graphs there are two graphs such that one is a minor of the other. This implies, as we shall see, that every minor-closed graph property can be described by a list of finitely many forbidden minors, massively generalizing the Kuratowski-Wagner theorem for planar graphs.

Our second point of emphasis, if time permits, will be on Hadwiger's conjecture: that every graph with chromatic number at least r has a K_r minor. We shall survey what is known about this conjecture, including some very recent progress.

Prerequisites: A solid background in the fundamentals of graph theory.
Format: There are two meetings per week (MO 9:45-11:15 and FR 11:30-13:00). The problem class will take place bi-weekly, replacing the Friday lecture slot. The course is tentatively planned to take place online with recorded lectures posted on the ILIAS platform, though we might have some problem classes in-person depending on the situation and the number of participants. There will be no written exam. An oral exam will take place at the end of the lecture period.

- **0100027 Numerical Simulations in Molecular Dynamics II**
  Instructor: PD Dr. Volker Grimm
  Weekly hours: 2+1

  This course is the second part of the lecture "Numerical Simulations in Molecular Dynamcis", which had been splitted due to the corona crisis. The course deals with the necessary numerical techniques of molecular dynamics in order to write a molecular dynamics program in the programming language C on serial and parallel computers with distributed memory. In the second part, emphasis will be on more complex molecules and time integration schemes.

  Prerequisites: The first part of the lecture.
  Lecture and tutorial will be online

- **0104600 Nonlinear boundary value problems**
  Instructor: Prof. Michael Plum
  Weekly hours: 4+2

  The lecture course will be concerned with boundary value problems for nonlinear elliptic partial differential equations, mainly of second order. In contrast to the linear case, no "unified" existence theory is at hand, but various approaches for proving existence (and other properties) of solutions

need to be studied. The methods investigated in the lecture course are subdivided into non-variational and variational methods. A preliminary and incomplete list of topics: motivating examples, monotonicity methods, fixed-point methods, super- and subsolutions, non-existence results, radial symmetry, a short introduction into variational calculus, Euler-Lagrange equations, variational problems under constraints, critical points, mountain pass theorem, perturbation results.
Prerequisites: Knowledge in functional analysis (Hilbert- and Banach spaces, weak convergence, dual space, Frechet differentiable operators) is essential, as well as the Lebesgue integral and Sobolev spaces. Knowledge in the classical theory of partial differential equations, and about weak solutions to linear problems, will be very useful.

The lectures will be given online in form of pre-recorded videos. Problem class: Fr. 8:00, SR 3.069..

- **0107800 Numerical methods in mathematical finance**
  Instructor: Prof. Tobias Jahnke
  Weekly hours: 4+2

  An option is a contract which gives its owner the right to buy or sell an underlying asset at a future time at a fixed price. The underlying asset is often a stock of a company, and since its value varies randomly, computing the fair price of the corresponding option is an important and interesting problem which yields a number of mathematical challenges. This lecture provides an introduction to a number of models for option pricing. The main goal, however, is the construction and analysis of numerical methods which approximate the solution of the corresponding differential equations in a stable, accurate and efficient way. The following topics will be treated:
  - Mathematical models for pricing stock options
  - Numerical methods for stochastic differential equations
  - Monte Carlo simulation and multilevel Monte Carlo methods
  - Monte Carlo integration and quasi-Monte Carlo methods
  - Finite difference methods for parabolic partial differential equations
  - Numerical methods for free boundary value problems

  Prerequisites: Participants have to be familiar with
  - probability theory (cf. lecture “Wahrscheinlichkeitstheorie”),
  - the Itô integral, the Itô formula, stochastic differential equations, and
  - programming in Matlab or Python.

Knowledge about stocks, options, arbitrage and other aspects from mathematical finance is not required, because the lecture will provide a short introduction to these topics.

Format: The course consists of a lecture and a problem class, both given in English. Because of the restrictions caused by the COVID-19 pandemic, the lecture will be given by means of videos in which the lecture notes are explained. Students will have the possibility to ask questions about the lecture in an inverted classroom session, which will take place every second week in a lecture room of the math building. Every week an exercise sheet will be published. The purpose of the exercises is to give a better understanding of results and concepts presented in the lecture. In some of the exercises students will be asked to write short programs in MATLAB or PYTHON in order to test and apply the algorithms introduced in the lecture. Instead of a classical problem class, solutions to the exercises will be provided for download. Every second week there will be a time slot where students can meet the tutor in person in order to ask questions about the exercises, the solutions, or to get help for the debugging of their codes.

- **0110300 Finite Element Methods**
  Instructor: Prof. Marlis Hochbruck
  Weekly hours: 4+2

  This lecture provides an introduction to the theory of finite element methods for elliptic boundary value problems in dimension one and two. In particular, stability and convergence will be proved and concepts for the implementation of such methods will be explained. Moreover, the numerical solution of elliptic eigenvalue problems and mixed methods for saddle point problems will be investigated.

  The students are expected to be familiar with the basics of numerical analysis, in particular interpolation, numerical integration, solution of linear systems and eigenvalue problems. Some basic knowledge in functional analysis and the analysis of boundary value problem is helpful but the main results will be repeated in the lecture.

  Lecture: Videos of all lectures will be provided in ILIAS
  Q&A Session (live and online): Tuesday, 5th block

Tutorial: Thursday, 2nd block (live and online, will include group work either online or in seminar rooms)

- **0111500 Algebraic TopologyII**
  Instructor: Prof. Roman Sauer
  Weekly hours: 4+2

  Algebraic topology studies topological spaces up to deformations with algebraic methods. To this end, we will construct a powerful functor from topological spaces to abelian groups: singular homology. Topics include Eilenberg-Steenrod axioms, comparison with simplicial homology and cellular homology. If time permits, we also discuss cohomology and its algebra structure.

  Prerequisites: topological spaces, basic facts about homotopy, van-Kampen theorem and its applications, basic notions from category theory
  Lecture: recorded videos
  Tutorial: Wed 9:45-11:15 SR 1.067 (current status; the time slots at KIT might be still changed!)

- **0118000 Asymptotic Stochastics**
  Instructor: Vicky Fasen-Hartmann
  Weekly hours: 4+2

  The aim of this class is to extend the classical central limit theorem of Lindeberg-Feller to the multivariate setting and get rid of the iid assumption. We use these results to prove the consistency and asymptotic normality of both parametric estimators (e.g. maximum-likelihood estimator) and nonparametric estimators (e.g. U-statistics), to construct asymptotic confidence intervals and consistent tests (e.g. likelihood ratio test). Moreover, we derive limit results in metric spaces and apply them as well in statistics.

  Prerequisites: Einfhrung in die Stochastik (Introduction to Probabitly and Statistics), Wahrscheinlichkeitstheorie (Probability Theory)
  Lecture: online
  Problem class: online

- **0120700 Microstructure in materials and fluid dynamics (seminar)**
  Instructors: JProf. Dr. Xian Liao, Dr. Christian Zillinger
  Weekly hours: 2

  Microstructure arises in many problems from materials science and fluid dynamics, giving rise to interesting behaviour but also to significant mathematical challenges. A famous example of this is the formation of turbulence in fluid flows. In this seminar we seek to study some aspects of the microstructure formation in prototypical settings and seek to explore how this influences the properties of the underlying PDEs.

  We will begin by investigating the Euler equations describing an inviscid fluid, and more precisely, we will study relaxed versions of the associated variational problem. This will lead to very weak, measure-valued notions for solutions, and we will study these "Brenier solutions" as well as "wild" convex integration solutions. In the second part of the seminar we will deal with mixing and methods of avoiding mixing in fluids and materials.

  Remarks: If you are interested in participating in the seminar, please write an email to zillinger@kit.edu. There will be an online meeting to distribute topics at the end of September. The seminar will be held as an online seminar together with some groups at Heidelberg University. Webpages: www.math.kit.edu/iana8/. www.uni-heidelberg.de/math/rueland/

  Prerequisites: Analysis I-III, functional analysis, introduction to PDEs.
  Mo 14:00-15:30

- **0123100 Forecasting: Theory and Practice (Part I)**
  Instructor: Prof. Tilmann Gneiting
  Weekly hours: 2+1

  A common desire of all humankind is to make predictions for the future. As the future is inherently uncertain, forecasts ought to be probabilistic, i.e., they ought to take the form of probability distributions over future quantities or events. In this class, which constitutes Part I of a two-semester series, we will study the probabilistic and statistical foundations of the science of forecasting.

  The goal in probabilistic forecasting is to maximize the sharpness of the predictive distributions subject to calibration, based on the information set at hand. Proper scoring rules such as the logarithmic score and the continuous ranked probability score serve to assess calibration and sharpness simultaneously, and relate to information theory and convex analysis. As a special case, consistent scoring functions provide decision-theoretically coherent tools for evaluating point forecasts. Throughout, concepts and methodologies will be illustrated in data examples and case studies.

Prerequisites: A firm understanding of the contents of module Probability Theory is essential.

- **0123400 Extremal Problems in Combinatorics (seminar)**
  Instructors: Prof. Maria Axenovich, Dr. Richard Snyder
  Weekly hours: 2

  This seminar will be based on a collection of recent papers in extremal combinatorics - a fast-growing field of discrete mathematics. The emphasis will be on extremal partially ordered set theory and extremal graph theory. Specific questions will include: Are there graphs that contain no induced copy of a graph H and loose this property after deleting or adding any edge? What is the largest number of elements in a Boolean lattice not inducing a given poset? How dense can a graph be so that there are only few paths of a prescribed length between any two vertices?

  Prerequisites: basic knowledge of graph theory, linear algebra, combinatorics
  Mo 14:00-15:30 20.30 SR 2.05

- **0121900 Seminar: Modeling, Algorithms, Simulation**
  Instructor: Prof. Frank, Dr. Kondov
  Weekly hours: 2

  Methods of computational science are essential for modern research and development in science, technology and economy. Numerous examples can be found in the fields of fluid mechanics, climate research and materials research. The mathematical modeling and algorithms used here are the focus of this seminar. The practical relevance and the optimal use of the models and algorithms and, in particular, the applications of these models and algorithms in computer simulations for concrete scientific problems, are especially emphasized. On the one hand, the optimal choice and further development of models and algorithms can significantly increase the efficiency, accuracy and reliability of simulations on high-performance computers. On the other hand, the solution of completely new scientific tasks is often based on already known models and algorithms. The topics offered for the seminar are based on current research and include mathematical-physical modeling, numerical and non-numerical algorithms as well as other methodological areas of scientific computing.

On selected topics, the students investigate current approaches to modeling and algorithms used in modern computer simulation. Students learn about practical applications of different models and numerical and non-numerical algorithms in research and development. The students deepen their knowledge in the assigned topic and critically examine literature sources and existing implementations. In doing so they try to reconstruct key points of a concrete work (a paper or a simulation code). The students learn to present their assigned topics to the topic supervisors (the tutors) and other students in an understandable way and to answer questions in a subsequent discussion. Finally, the students will summarize their results in a written work (an article) and learn to write scientific texts.

- **0155450 Introduction to Kinetic Theory**
  Instructor: Prof. Martin Frank
  Weekly hours: 2+1

  Kinetic descriptions play an important role in a variety of physical, biological, and even social applications, for instance, in the description of gases, radiations, bacteria or financial markets. Typically, these systems are described locally not by a finite set of variables but instead by a probability density describing the distribution of a microscopic state. Its evolution is typically given by an integro-differential equation. Unfortunately, the large phase space associated with the kinetic description has made simulations impractical in most settings in the past. However, recent advances in computer resources, reduced-order modeling and numerical algorithms are making accurate approximations of kinetic models more tractable, and this trend is expected to continue in the future. On the theoretical mathematical side, two rather recent Fields medals (Pierre-Louis Lions 1994, Cdric Villani 2010) also indicate the continuing interest in this field, which was already the subject of Hilbert's sixth out of the 23 problems presented at the World Congress of Mathematicians in 1900.

This course gives an introduction to kinetic theory. Our purpose is to discuss the mathematical passage from a microscopic description of a system of particles, via a probabilistic description to a macroscopic view. This is done in a complete way for the linear case of particles that are interacting with a background medium. The nonlinear case of pairwise interacting particles is treated on a more phenomenological level.

An extremely broad range of mathematical techniques is used in this course. Besides mathematical modeling, we make use of statistics and probability theory, ordinary differential equations, hyperbolic partial differential equations, integral equations (and thus functional analysis) and infinite-dimensional optimization. Among the astonishing discoveries of kinetic theory are the statistical interpretation of the Second Law of Thermodynamics, induced by the Boltzmann-Grad limit, and the result that the macroscopic equations describing fluid motion (namely the Euler and Navier-Stokes equations) can be inferred from abstract geometrical properties of integral scattering operators.

Prerequisites: none
Recommended courses: Partial Differential Equations, Functional Analysis

The description for Functional Analysis (Prof. Hundertmark) is not available yet.

See also https://www.math.kit.edu/vvz/seite/vvzkommend/de