MASTER DEGREE COURSES OFFERED IN ENGLISH IN SUMMER SEMESTER 2020

- **0110650 Numerical Linear Algebra for Scientific High Performance Computing**
  Instructor: Dr. Hartwig Anzt
  Weekly Hours: 2
  Lecture Mo 8:00-9:30

  This course covers the fundamentals of designing and implementing numerical linear algebra operations and algorithms on modern multi- and manycore architectures. It bridges between mathematical theory on PDEs, discretization, linear solvers, iteration methods, and preconditioning and programming aspects like MPI, OpenMP and GPU programming:
  -We start with an overview about HPC, current trends in high-end computing systems and environments, and continue with an introduction of common architecture designs and programming methodologies.
  -We then take a deeper dive into programming techniques for multi- and manycore. We will learn OpenMP and CUDA programming. Besides that, we will look at performance modeling and tools that allow to assess the efficiency of implementations when running in parallel.
  -We look into direct and iterative solution methods for linear problems: LU, QR, Cholesky, Relaxation Methods, Krylov Methods, Multigrid methods. For the iterative solution methods, we also cover the concept of preconditioning, and the most common techniques like (Block-) Jacobi preconditioning, Incomplete Factorization Preconditioning (ILU), Sparse Approximate Inverses (SAI).
  -The last part of the course is the presentation of the student projects. Each student chooses a topic in agreement with the lecturer, and prepares a presentation along with a project class paper. This project accounts for 60% of the course grade. Although students are encouraged to come up with their own project ideas, a list containing possible topics will be distributed at the beginning of the course.

- **0150300 Combinatorics**
  Instructor: Prof. Maria Axenovich
  Weekly Hours: 4+2
  Lecture: Tu 9:45-11:15 Fri 11:30-13:00

Problem class: Mon 11:30-13:00

Combinatorics is the study of counting or enumerating arising from sets, groups, graphs and other discrete objects in mathematics. While combinatorics problems are often very basic and easy to describe, solving them requires special knowledge and skills. This course is devoted to basic concepts and techniques in combinatorics. These include counting principles such as inclusion-exclusion and bijective mappings, twelvefold way, generating functions, arrangements, Young tableaux, recursions, partially ordered sets, and designs.

Prerequisites: Linear algebra.

- **0152600 Stochastic Geometry**
  Instructor: PD Dr. Steffen Winter
  Weekly Hours: 4+2
  Lecture: Mon 14:00-15:30, Thu 11:30-13:00
  Tutorial: Fri 14:00-15:30

  In Stochastic Geometry mathematical models are developed for describing and analyzing random geometric structures. The course provides an introduction to this field which is also highly interesting from an applied point of view with applications e.g. in material science, telecommunication or cell biology. Stochastic Geometry combines methods from probability theory (in particular point processes, random sets and random measures) with concepts from convex and integral geometry (intrinsic volumes, kinematic formulas, Crofton formulas). In the centre are germ-grain models, in particular the Boolean model, and random tessellations. Specific topics to be covered include: random closed sets, stationarity and isotropy, Poisson and related point processes, germ-grain models and Boolean models, the Steiner formula and intrinsic volumes, the principal kinematic formula, the Crofton formula, specific intrinsic volumes, contact distributions, random tessellations.

  Prerequisites: Probability theory (including some measure theory); Basic knowledge in convex geometry is helpful, but not required. The course "Spatial Stochastics" (offered each winter term) is recommended but not required.

- **0156400 Evolution Equations**
  Instructor: Prof. Roland Schnaubelt
  Weekly Hours: 4+2
  Lecture: Mo 9:45-11:15, We 8:00-9:30
  Tutorial: Fr 9:45-11:15

  Evolution equations describe the time evolution of dynamical systems by an ordinary differential equation in a Banach space. We investigate linear and autonomous (time invariant) problems. In this case the solutions are given by a one-parameter semigroup of linear operators. For such operator semigroups there is a quite complete theory, which allows us to study the properties of the underlying dynamical system. This approach essentially relies on functional analytic methods and results.

  We treat the basic existence theorems for linear autonomous evolution equations. In this framework, we then investigate qualitative properties of the solutions, such as regularity and the longterm behavior. Perturbation and approximation results are also studied (which have connections to numerical analysis). The developed theory can be applied to the diffusion, the (damped) wave, and the Schrdinger equation.

  Prerequisites: Knowledge of the lecture Functional Analysis and of the theory of L^p spaces.

- **0156500 Nonlinear Wave Equations**
  Instructor: Dr. Birgit Schörkhuber
  Weekly hours: 2+1
  Lecture: Fri 11:30 - 13:00
  Problem class: Th 15:45 - 17:15

  Wave equations are ubiquitous and play a fundamental role in physics and applications. In many models, nonlinearities appear naturally and introduce highly non-trivial dynamics. The aim of this course is to give an introduction into the mathematical analysis of nonlinear wave equations. Central questions concern the existence of solutions to the initial value problem (local/global well-posedness), the description of long-time behaviour, as well as the formation of singularities. Starting with a modern view on the linear wave equation, we will investigate nonlinear problems by means of energy estimates, tools from harmonic analysis (Strichartz type estimates) and geometric methods (vector field methods).

Prerequisites: Basic knowledge of functional analysis; Fourier transform; distributions; weak derivatives (some basics will also be repeated at the beginning of the course)

- **0157400 Algebraic Topology**
  Instructor: Prof. Roman Sauer
  Weekly hours 4+2
  Lecture: Thu 14:00-15:30 Fri 9:45-11:15
  Tutorial: Wed 9:45-11:15

  Algebraic topology studies topological spaces up to deformations. To this end, we construct algebraic invariants associated with topological spaces. The topics to be covered include: classification of surfaces, basic homotopy theory, fundamental group and van Kampens theorem, covering theory.

  Prerequisites: basic notions of topological spaces and continuity as known from the Analysis I,II. Basic notions like groups as known from Lineare Algebra I, II.

- **0157500 Boundary and Eigenvalue Problems**
  Instructor: Prof. Plum
  Weekly hours: 4+2
  Lecture: Tu 14:00-15:30, Th 11:30-13:00
  Tutorial: Wed 15:45-17:15

  A boundary value problem consists of an elliptic (or ordinary) differential equation posed on some domain, together with additional conditions required on the boundary of the domain, e.g. prescribed values for the unknown function. Typical origins of boundary value problems are steady-state (i.e. time-independent) situations in physics and engineering. An eigenvalue problem for a differential equation is a linear and homogeneous boundary value problem depending (typically linearly) on an additional parameter, and one is interested in values of this parameter such that the boundary value problem has nontrivial solutions. Eigenvalue problems arise e.g. after separation of variables in time-dependent problems (thus describing many vibrational situations, including quantum mechanics). The lectures will be accompanied by exercise lessons. Attendance of these exercises is strongly recommended to all participants.

Prerequisites: The lecture course addresses students in their sixth semester (third year) or higher, with substantial knowledge in analysis and linear algebra.

References:
A. Friedman: Partial Differential Equations (general elliptic PDE of order 2m, but smooth data only)
D. Gilbarg, N. Trudinger: Elliptic Partial Differential Equations of Second Order (elliptic PDE of second order, mainly Dirichlet b.c.)
L. C. Evans: Partial Differential Equations
R. A. Adams: Sobolev Spaces (no PDE's, but excellent and general introduction into Sobolev spaces, an essential tool in PDE theory)

- **0160000 Probability Theory and Combinatorial Optimization**
  Instructor: Prof. Dr. Daniel Hug
  Weakly Hours: 4+2
  Lectures: Wed 11:30-13:00, Th 09:45-11:15
  Tutorial: Wed 09:45-11:15, Mon 15:45-17:15 (reserved for additional lectures)

  This course is devoted to the analysis of algorithms and combinatorial optimization problems in a probabilistic framework. A natural setting for the investigation of such problems is often provided by a (geometric) graph. For a given system (graph), the average or most likely behavior of an objective function of the system will be studied. In addition to asymptotic results, which describe a system as its size increases, quantitative laws for systems of fixed size will be described. Among the specific problems to be explored are
  -the long-common-subsequence problem,
  -packing problems,
  -the Euclidean traveling salesman problem,
  -minimal Euclidean matching,
  -minimal Euclidean spanning tree.
  For the analysis of problems of this type, several techniques and concepts have been developed and will be introduced and applied in this course. Some of these are
  -concentration inequalities and concentration of measure,
  -subadditivity and superadditivity,
  -martingale methods,
  -isoperimetry,
  -entropy.

Exercises: Exercises and their solutions will be available in the Ilias platform.

Literature:

Boucheron, S., Lugosi, G., Massart, P. Concentration Inequalities, Oxford University Press, Oxford, 2013.
Dubhashi, D., Panconesi, A. Concentration of Measure for the Analysis of Randomized Algorithms, Cambridge University Press, Cambridge, 2009.
Ledoux, M. The Concentration of Measure Phenomenon. American Mathematical Society, vol. 89, 2001.
Steele, J.M. Probability Theory and Combinatorial Optimization. SIAM, 1997.
Yukich, J.E. Probability Theory of Classical Euclidean Optimization Problems. Lecture Notes in Mathematics, Vol. 1675, Springer, Berlin, 1998.

- **0160800 Splitting methods for evolution equations**
  Instructor: Prof. Dr. Tobias Jahnke
  Weekly hours: 3+1
  Lecture: Mon 11:30-13:00, Fri 11:30-13:00 (every 2nd week),
  Problem class: Fri 11:30-13:00 (every 2nd week), Benny Stein

  Splitting methods are a very popular class of integrators solving time-dependent ordinary or partial differential equations numerically. The underlying idea is to decompose the differential equation into two or more subproblems which can be solved exactly or more efficiently, and to construct an approximation of the full problem by a suitable composition of the flows of the subproblems.

  After a short introduction to splitting methods for ordinary differential equations, the lecture will focus on splitting methods for partial differential equations such as, e.g., linear and nonlinear Schrdinger-type equations and parabolic problems. Special attention will be given to the convergence analysis, in particular to the relation between the order of convergence and the regularity of the data. This will require some results from semigroup theory, which will be provided in the lecture.

  Prerequisites: Students are expected to be familiar with ordinary differential equations, Runge-Kutta methods (construction, order, stability) and Sobolev spaces (definition, basic properties, Sobolev embeddings).

- **0161100 Time Series Analysis**
  Instructor: Prof. Gneiting

Weekly Hours: 2+1
Lecture: Tu 14:00-15:30
Tutorial: Mo 8:00-9:30

A time series is a sequence (x_t) of data where the subscript t indicates the time at which the datum x_t was observed. The course provides an introduction to the theory and practice of statistical time series analysis. Topics covered include stationary and non-stationary stochastic processes, autoregressive and moving average (ARMA) models, state-space models and the Kalman filter, model selection and estimation, forecasting and forecast assessment, and an outline of spectral techniques.

Prerequisites: Basic concepts of probability theory and statistics.

- **0164400 Uncertainty Quantification**
  Instructor: Prof. Martin Frank
  Weekly Hours: 2+1
  Lecture: Thursday 8:00-9:30
  Problem class: Thursday 15:45-17:15

  In this class, we learn to propagate uncertain input parameters through differential equation models, a field called Uncertainty Quantification (UQ). Given uncertain input (parameter values, initial or boundary conditions), how uncertain is the output? The first part of the course ("how to do it") gives an overview on techniques that are used. Among these are:
  Sensitivity analysis
  Monte-Carlo methods
  Spectral expansions
  Stochastic Galerkin method
  Collocation methods, sparse grids.

  The second part of the course ("why to do it like this") deals with the theoretical foundations of these methods. The so-called "curse of dimensionality" leads us to questions from approximation theory. We look back at the very standard numerical algorithms of interpolation and quadrature, and ask how they perform in many dimensions.

  Prerequisites: Numerical methods for differential equations

- **0178100 Mathematical Methods in Quantum Mechanics Part II**
  Instructor: Dr. Ioannis Anapolitanos
  Weekly Hours: 4+2
  Lecture: Tu 11:30-13:00, Fr 14:00-15:30
  Tutorial: Wed 14:00-15:30

  This course goes deeper in the fundamental questions of the Mathematical Theory of quantum mechanics. With the gained knowledge the students can understand and analyze fundamental results of interacting quantum many-body systems. In the course subjects like scattering Theory, many-body systems, Fock spaces and second quantization will be discussed. Then various models will be considered like the Bardeen-Cooper-Schrieffer model of the superconductivity (BCS-Theorie), the Hartree Fock approximation, Polarons and other models of interacting quantum many-body systems. It will also be discussed how nonlinear interactions can arise from many-body systems.

  Prerequisites: Functional Analysis, Spectral Theory, Previous knowledge of quantum mechanics.

- **0178200 Numerical Simulations in Molecular Dynamics**
  Instructor: Volker Grimm
  Weekly Hours: 4+2
  Lecture: Tu 08:00-09:30, Wed 11:30-13:00
  Tutorial: Mo 15:45-17:15

  This 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.

  Prerequisites: Time integration of ordinary differential equations, experience in C programming.

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