Tuesday, August 30, 14:00, Room MA005

Sufficient Conditions of Optimality for Optimal Control Problems Governed by Integral Operators

Armin Hoffmann, TU Ilmenau

For special problems of the type

$$f(x,u) \longrightarrow \inf$$
$$g(x,u) \in K$$
$$x \in M, u \in U$$

where f is an integral functional, g is a nonlinear integral operator, K is a convex and closed cone in a Banach space we consider sufficient conditions of optimality. The conditions work local with respect to the state x and global with respect to the control u by using some generalized Lagrangian. In the first case we have to verify functional relations and in the second case we look for as much as possible pointwise conditions. Simple examples show the use of the sufficient criteria.

Tuesday, August 30, 14:30, Room MA005

On Structural Stability in Nonlinear Optimization and Control

Gerhard-Wilhelm Weber, Technische Hochschule Darmstadt

We study global stability of differentiable control problems on minimizing an integral functional w.r.t. a differential equation, finitely many state restrictions and boundary conditions of equation or inequality type.

Two problems are called *equivalent* if each lower level set is mapped homeomorphically onto a corresponding lower level set of the other problem. In case that a given problem is equivalent with all the problems that belong to some neighbourhood of the defining control and functional data of our problem, we call it *structurally stable*. Under the assumption that the set of feasible state functions is compact we prove that structural stability is equivalent with the validity of the following conditions:

C1. The *Mangasarian-Fromovitz constraint qualification* holds at each feasible state function.

C2. Every Kuhn-Tucker trajectory is *strongly stable*.

C3. Different Kuhn-Tucker trajectories have different values.

We give the sufficiency part and the necessity part of the proof in a dynamical and in a perturbational way (resp.) translating the information of our optimal control problem into the language of nonlinear optimization. Finally we present generalizations and applications.

Tuesday, August 30, 15:00, Room MA005

Applications of Sensitivity Analysis for Parametric Control Problems with Constraints

Helmut Maurer, Westfälische Wilhelms-Universität Münster

The paper is concerned with the following *parametric nonlinear control* problem $OC(p)$ depending on a parameter p in a Banach space P: Minimize

$$g(x(b),p) + \int_a^b L(x(t),u(t),p)dt$$

subject to

$$\dot{x}(t) = f(x(t),u(t),p)\ ,\ \varphi(x(a),x(b),p) = 0\ ,$$

and mixed control-state constraints

$$C(x(t),u(t),p) \leq 0 \quad \text{for} \quad a \leq t \leq b\ .$$

The functions $g : R^n \times P \to R$, $L : R^{n+m} \times P \to R$, $f : R^{n+m} \times P \to R^n$, $\varphi : R^{2n} \times P \to R^r$ and $C : R^n \times R^m \times P \to R^k$ are assumed to be C^2-functions. The problem $OC(p_0)$ corresponding to a fixed reference parameter $p_0 \in P$ is considered as the unperturbed problem. Stability conditions are given such that the following sensitivity result holds:

Solution differentiability: the solutions $x(t,p), u(t,p)$ of $OC(p)$ and the associated adjoint function $\lambda(t,p)$ are C^1-functions with respect to (t,p) for all p in a neighborhood of p_0 and for a.e. $a \leq t \leq b$.

The literature has a deficit of concrete numerical examples illustrating stability results and sensitivity analysis. We shall discuss three **non-convex** examples which demonstrate the interplay between the following essential ingredients for solution differentiability: (a) Second-order sufficient conditions ; (b) Controllability; (c) Junction conditions.

Tuesday, August 30, 15:30, Room MA005

Degenerated Quadratic Forms in Calculus of Variations

Aram Arutyunow, Russian Friendship University, Moscow

An important problem in the calculus of variations is the problem of obtaining necessary and sufficient conditions for nonnegativity of quadratic forms.It is well known that the Legendre conditions are necessary for nonnegativiness.Also if the strong Legendre conditions violates,i.e.the quadratic form degenerates then the investigation of them becomes very difficult.In this report new necessary and sufficient condi- tions of nonnegativiness of degenerated quadratic forms are obtained.

Semi-Plenary Lecture
Wednesday, August 31, 09:00, Room MA005

Limit Cycles in Slow - Fast Dynamical Systems

Sergio Rinaldi, Politecnico di Milano

A method for detecting limit cycles in slow - fast dynamical systems is presented and applied to problems of particular interest including alternation between despotism and anarchy in societies, renewable resources management and corruption in democratic systems. The analysis is based on singular perturbation arguments, and the limit cycles that the method identifies are composed of alternate slow and fast transitions.

The procedure is very simple and purely geometric: if the equilibrium manifold of the slow variable separates the stable equilibrium sub-manifolds of the fast system, a stable cycle exists in the limit case of highly differentiated dynamics.

The systematic application of the method seems very promising for discussing the behavior of economic systems, which are very often the aggregation of fast and slow components.

Wednesday, August 31, 10:00, Room MA005

A Simple Test to Accompagny the Nearest Neighbor Forecasting Approach to Distinguish Chaos from Noise

Bärbel Finkenstädt, Freie Universität Berlin
Peter Kuhbier, Freie Universität Berlin

This paper is based on a recent nonparametric forecasting approach by Sugihara and May [1990] to discriminate between nonlinear chaotic processes and measurement error. The idea underlying their forecasting algorithm is briefly stated as follows: For a nonlinear low-dimensional process, a phase space embedding of the observed time series exhibits "spatial" correlation, which can be exploited to improve *short term* forecasts by means of locally linear approximations. Of course, such an approach could not be fruitful in the case of a random series. Therefore, the forecast performance of the algorithm constitutes a potential measure of distinguishing between chaotic and random processes. Still, the important question of evaluating the forecast perfomance is very much an open one, if the researcher is confronted with data that are additionally disturbed by stochastic noise. To account for this problem, an extremely simple nonparametric test to accompany the algorithm is suggested here. To demonstrate its practical use, the methodoloy is applied to observed economic time series from agricultural markets, and obtains better short term predictions than the best fitting linear autoregressive model.

Wednesday, August 31, 10:30, Room MA005

Periodic and Chaotic Solutions of Dynamic Programs

Gustav Feichtinger, University of Technology, Vienna
Herbert Dawid, University of Technology, Vienna

The paper is concerned with one-state deterministic infinite-time intertemporal optimization models. It is shown that several dynamic programming models may exhibit complex policies, i.e. cyclical and aperiodic solution paths. Emphasis is placed on the emergence of chaos. Our aim is to identify mechanisms generating complicated behaviour for dynamic optimization models arising in various fields of OR. Among them are marketing, resource management, and queueing theory.

Wednesday, August 31, 14:00, Room MA005

Optimal Investment and Finance in Renewable Resource Harvesting

Steffen Jörgensen, Odense University
Peter M. Kort, Tilburg University

We study an optimal control problem in natural resource harvesting, e.g., a sole-owner commercial fishery. The owner can invest/disinvest in "production capacity"(number of vessels per year) and may finance his operations with retained earnings or debt. Moreover, financial investment (i.e., lending) is possible. The approach combines two different streams of research: resource harvesting with capital investments, and investment policy under financial constraints. After a simplification, the model contains two states (resource stock and stock of equity) and two controls (harvesting effort rate and dividend payout rate). The solution is identified by the Maximum Principle, a synthesizing procedure, and computer simulations of a 3-dimensional system of ODE's. ¡ please type

Wednesday, August 31, 14:30, Room MA005

Input Substitution Subject to Environmental Constraints

Richard F. Hartl, Universität Magdeburg, Germany
Peter M. Kort, Tilburg University, The Netherlands

In this paper we consider the dynamic behaviour of a firm subject to environmental regulations. The abatement process is modelled as input substitution rather than end-of-pipe. In particular, we investigate under which circumstances the firm should switch from a cheap and polluting input (high sulphur coal) to a more clean but more expensive one.

Using standard control theory in determining the firm's optimal dynamic investment decisions it turns out that it is always optimal to approach a long run optimal level of capital. In some cases, this equilibrium is reached within finite time, but usually it will be approached asymptotically. Also a necessary condition is determined under which history dependent equilibria can occur.

Finally, we derive conditions under which equilibrium capital stock and equilibrium investment rate in the regulated case decrease compared to the unregulated case.

In the model we also permit that production capacity can remain unused if the capital stock is high and the emission limit is tight. It is shown that for large capital stocks or tight emission limits, it can be optimal to actually leave some production capacity unused. Furthermore, it can be optimal to choose a positive investment rate and at the same time to leave production capacity unused.

Wednesday, August 31, 15:00, Room MA005

Marketable Permits in a Stochastic Dynamic Model of the Firm

Richard F. Hartl, University of Magdeburg
Peter M. Kort, Tilburg University

This contribution belongs to a category of papers that attempts to determine the effects of environmental regulation on the growth of an individual firm. Here, it is assumed that the firm's revenue is stochastic. The government tries to reduce pollution by creating a market on which the firm has to buy permits in order to be allowed to pollute the environment. Pollution is an inevitable byproduct of the firm's production process

and in our model the firm is offered two ways to deal with it. the first is to buy marketable permits and the second is to clean up pollution which can be achieved through investing in abatement capital stock. It turns out that the firm's optimal trajectory consists of at most seven different policies. They occur in a feedback diagram out of which we can conclude that, provided that the firm never faces a shortage of cash money, productive and abatement capital stock ultimately reach their equilibrium levels where marginal revenue equals marginal costs.

Wednesday, August 31, 15:30, Room MA005

Some Structure Optimization Problems of Hierarchic Systems

Vladimir Dementiev, Russian Academy of Sciences, Siberian Branch
<u>Adil Erzin</u>, Russian Academy of Sciences, Siberian Branch

Many complex control and communication systems are organized by hierarchic principle. Optimal structure of such systems - often the main in their effective functioning. In this paper considered some initial (basic) models and problems of structure optimization of multilevel hierarchic systems. Such problems arise attached to administration system optimization over homogeneous objects. Some characteristics of the problems are obtained. Offed some effective methods.

Wednesday, August 31, 16:30, Room MA005

Strategisches Preismanagement bei Sättigungseffekten

Engelbert J. Dockner, Universität Wien
<u>Andrea Gaunersdorfer</u>, Universität Wien

Wir betrachten einen heterogenen Duopolmarkt, auf dem zwei Unternehmungen Gebrauchsgüter absetzen. Die Nachfrage der Güter wird durch lineare Preis-Absatz-Funktionen mit Sättigungseffekten beschrieben. Beide Unternehmungen agieren mit konstanten Stückkosten und verfolgen langfristige Ziele, d.h. sie maximieren den Barwert zukünftiger Gewinne über einen unendlichen Planungshorizont. Die optimalen Preise werden als Nash-Gleichgewichtspreise mit Strategien in geschlossener Schleife abgeleitet. Es zeigt sich, daß die optimalen dynamischen Preise im Falle einer strikt positiven Diskontrate konstant und höher als die statisch-gewinnmaximalen sind. Vernachlässigt man die Abzinsung zukünftiger Gewinne, so existiert neben einem Gleichgewicht in konstanten auch eines mit monoton steigenden Preisen.

Wednesday, August 31, 17:00, Room MA005

Natural Resources and Pollution - Cooperative and Non-Cooperative Equilibria

<u>Martin Schäfer</u>, Universität der Bundeswehr, Hamburg

Natural environments like fishing areas or forests are more and more damaged by several sorts of pollutive materials. These materials are waste residuals due to production processes or to consumption of certain consumption goods. In this paper we assume two aggregate decision makers: The first one controls the harvesting rate of a renewable resource (fish, timber, etc.), the second one controls the production of a certain consumption good which leads to waste residuals polluting the environment. The stock size of

the resource is influenced by the amount of waste residuals circulating in the environment, and the stock size of circulating pollutants is diminished by the recreation effect of nature. The "production costsöf the consumption good are assumed to depend either on the stock of nature or on the stock of pollutants. I.e. the damage of nature due to the emission of waste residuals lead to higher production costs of the consumption good. This constellation is modelled by a nonzero-sum differential game. Non-cooperative and cooperative equilibria are derived and compared with each other. The structure of the game (state separability) leads to degenerate feedback equilibria.

Wednesday, August 31, 17:30, Room MA005

A Reduction Technique For Deriving Feedback Strategies of a Class of Infinite Horizon Games

David W. K. Yeung, The University of Hong Kong
Lai-Yee Yeung, American Consulate General-Hong Kong

Solving a feedback Nash equilibrium (FNE) solution for a differential game requires the solving of a system of Hamilton-Jacobi-Bellman (HJB) equations. The inherent difficulties associated with solving systems of differential equations present a major stumbling lock for the applicability of FNE despite the subgame perfect property of the equilibrium. The present analysis develops a reduction technique which converts the solving of the FNE strategies into the solving of a normal system of ordinary differential equations for the following class of infinite horizon games.

$$\max_{u_i(s)} \int_0^{\inf ty} g^i[u_1(s), u_2(s), \ldots, u_n(s), x(s)] \exp(-r_i s) ds$$

$i = 1, 2, \ldots, n,$

subject to state dynamics:

$$\dot{x}(x) = f[u_1(s), u_2(s), \ldots, u_n(s), x(s)] \qquad x(O) = x_0$$

In particular, the technique will not be plagued by the problem of the absence of a substitutable (into the HJB equations) solution of the pointwise optimality conditions. Since analytical and numerical methods for solving normal systems are most developed among solution methods for systems of differential equations, the solubility of FNE can be enhanced.

Thursday, September 1, 09:00, Room MA005

Methods of Constructing Optimal Feedback Controls

Rafail Gabasov, Belarus State University

It is described an approach to the problem of constructing estimators and algorithms of acting optimal controllers in real time mode. The theory of optimal synthesis is applied to solve optimal stabilization problems for linear dynamic systems under uncertainty using bounded controls. An approach to solve the classical steering problem(getting on a given set) for dynamic systems under conditions of constantly acting perturbations is proposed. The results are illustrated by non-trivial examples.

Thursday, September 1, 09:30, Room MA005

Model Uncertainty - Complexity Balancing in Quasinormalization-Based Control

Sergey Chemishkian, American University of Armenia
Elena Meroyan, State Engineering University of Armenia

We consider a class of multivariable plants, defined by a set of possible linearized models (frequency-response matrices), each separate model corresponding to a certain stabilization / linearization point in operating regimes set. The whole set of models should be controlled by an output feedback with a single linear (robust) controller, which implements quasinormalization, alias improved Reversed Frame Normalizing Compensator (RFNC) control. The following results are presented in the paper:

- complexity of a plant nominal model determines complexity of compensator and design (three complexity indices, special for the RFNC control).
- a relationship exists between complexity and uncertainty (over the set of models) of a plant nominal model.
- complexity and uncertainty are influenced both by a nominal model selection and by a model I/O dynamic scaling.

Optimal complexity - uncertainty via simultaneous optimization of nominal model and I/O scaling factors is shown to be of crucial importance for model / control matching and successful control design.

Thursday, September 1, 14:00, Room MA005

Singular Control Problems as ill-posed Problems

Maria del Carmen Perez Cabrera, Universität Havanna

Optimal Control Problems with state constraints and singular arcs in the optimal solution have been treated by indirect methods with success by Bulirsch and his group . Usually, the state constraint $g(x,.) = 0$ or the equation describing the singular arc $\Phi(t, x, \lambda) = 0$, is differentiated until it is possible to obtain a relation of the form $u = R(x, \lambda)$, and then the system of necessary optimality conditions (maximum principle) is transformed into an ODE. In this case indirect methods make use of the multiple shooting method for the numerical solution of BVP for ODE's.
Another approach has been followed by Baeger , Döring and März where the singular arcs are considered as ill-posed problems in the sense of Tichonov. Here a regularization term is introduced in the objective functional and finally it is possible to obtain an ODE from the system of optimality conditions.
We consider the system of optimality conditions as a differential algebraic equation (DAE) and we use the methods developed by Griepentrog, März et al., for its solution. In case of singular arcs we establish that the corresponding DAE for the description of the optimality conditions has an index greater than one, as one should expect from the ill-posedness of singular control problems.
We use different index reduction methods for DAE's, and for the numerical solution of the TPBVP we use a Shooting Method for DAE's developed by R. Lamour. Preliminary computational experience is presented.

Thursday, September 1, 14:30, Room MA005

Numerical Treatment of a Shape Optimization Problem in Thermoelasticity

Jürgen Sprekels, Institut für Angewandte Analysis und Stochastik Berlin
Helmuth Goldberg, Technische Universität Chemnitz–Zwickau
Fredi Tröltzsch, Technische Universität Chemnitz–Zwickau

A shape optimization problem connected with the thermal deformation of elastic bodies is considered. Based on a finite element discretization of the thermoelastic system, a gradient method for solving the associated nonlinear programming problem is discussed. Several approaches to calculate the needed gradients are investigated.

Thursday, September 1, 15:00, Room MA005

Discrete Optimization Problem for Discrete-Continuous Processes

WajsWieslaw, University of Mining and Maetallurgy, Krakow

The paper concerns the operation sequences control of dynamic continuous processes. The duration of the operation is given by the function p(i,t). The set of input data for the optimisation problem is finite, i=1,...,n. The aim of the control is to determine a moment when precedence operation ended, and successive operation started. An objective function is defined as the total time for realisation all operations t(n)=t(n-1)+p(n,t). The aim of the optimisation is to find the optimal sequence for given form of the objective function. The paper suggests a formulation of the optimisation problem as well as a method for its solutions. The problem may be described as the determination of an optimal sequence for activities on resources. Each activity on resources is simulated by a mathematical model of the dynamic process. Dynamic processes are realised without an interruption and without idle time between them.

Thursday, September 1, 15:30, Room MA005

Optimization Problem of Land- and Board Control Complex Software

Igor Kovalev, Siberian Aerospace Academy

The optimization problem of the land-and board control complex software is a logical development of the choice problem of algorithms for functions realization in the flying vehicle control systems with regard for intercommunication on the information processing process and with regard for control functions allocation between land control complex and board control complex of spacecrafts. This problem is a real pseudoboolean optimization problem (discrete programming problem). The review of the discrete optimization methods and their software represented in the report shows that, apparently, the only efficient method for a solution of the real psedoboolean optimization problems is the adaptive random search algorithm. This algorithm is a basis of the method discussed in the report. We make use of the method of variable probabilities for solution of the indicated above problems. The organization of software tools of optimization-based design allows to solve our problems for minimal input. In the cited scheme is effective for the modular software, where each program module realizes concrete algorithm of the variable probabilities method. The organization scheme of an aposteriori identification of the purposeful functional of problem depends on the represented in report classification. In the report the reliability estimate of identification is given also.

Friday, September 2, 10:30, Room MA005

Optimal Macroeconomic Policies with Varying Time Horizon

Reinhard Neck, University of Bielefeld
Sohbet Karbuz, University of Technology, Vienna

The sensitivity of the solutions of optimum control problems with respect to the planning horizon has been treated in the theoretical literature, but mainly for small models (one state, one control variable). In this paper, we consider the above problem for a numerically specified model consisting of several dynamic equations, namely for a macroeconometric model for Austria. We show how extensions of the planning horizon affect optimal monetary and fiscal policies under certainty and under uncertainty within the framework of quantitative economic policy.

Friday, September 2, 11:00, Room MA005

Optimal Monthly Operation of the Rio Conchos System

Absalon Romero, Fundacion Universidad de las Americas-Puebla, Mexico

An optimal control algorithm based upon Pontryagin's maximum principle is applied to multireservoir network control in the Rio Conchos System. The method is computationally efficient and has minimal storage requirements. According to the industrial, urban and agricultural development in that region of Mexico, the Rio Conchos System's operation policies become an importan matter for those purposes. Results are presented.

Friday, September 2, 11:30, Room MA005

Analytical Solutions in the Calculate Algorithms of Discrete Multistage Optimization

Regina Nijole Simeliene, Lithuanian Scientific Society, Vilnius
Vilius Bistrickas, Lithuanian Scientific Society, Vilnius

Dynamic programming algorithms of approximation in the control space are used to investigate optimal solutions of discrete multistage optimization problems. Monotonicity of algorithms is considered. Using these algorithms is based on the analytical solutions of poly-choice gold mining problems, capital investment problems and regulator problems. Pure universal solutions of the poly-choice gold mining problems are given. Mixed analytical solutions for the wider class of discrete multistage optimization problems are obtained. New type monotonic discrete time control process and new type continuous time control processes are used to investigate mixed solutions.

Friday, September 2, 15:30, Room MA005

New Legendre Type Conditions for Optimal Control Problems, Linear in the Control

Andrei Dmitruk, Central Economic-Mathematical Institute, Moscow, Russia

no abstract received

Friday, September 2, 16:00, Room MA005

The Second Order Minimax Algorithms for the Optimization Problems with Disturbance

Evgene S. Polovinkin, Moscow Institute of Physics and Technology
Grigory E. Ivanov, Moscow Institute of Physics and Technology

This paper deals with a constructive technique of solving the problem of control synthesis for a linear controlled system under unknown but bounded disturbances v(t) in such a way that allows an algorithmization with an appropriate graphic simulation. The original theoretical solution scheme taken for our investigation comes from the theory introduced by L.S.Pontriagin and N.N.Krasovski, where was described the solvability set named as the 'alternated integral' and the control strategy u(t,x,v) can be constructed on the basis of the solvability set provided the letter is calculated in advance. We create the numerical minimax algorithms of calculation of the alternated integral when the letter has the nonempty interior. We investigate their speed of convergence in Hausdorff metric to the exact value for strongly convex prob- lems. It means the terminal and control subsets are strongly convex subsets, that is an every such subset can be constructed as an intersection of balls with fixed radius for this one. We investigate the constructive discretizations both by the time interval and by the support directions (the latter means the poly- hedral and convex approximations for the set-valued 'alternated sums') in the algorithms. We proved that the condition of strongly convexity of problem is the necessary and sufficient condition for the second order of the convergence the 'alternated sums' to the alternated integral by diameters of partitions of the time interval and of the conjugate sphere for the choosing support directions.

Friday, September 2, 16:30, Room MA005

Optimal Placement of Sensors and Actuators for a Beam Figure Control Problem

Sergey Chemishkian, American University of Armenia

Considered is a problem of a beam (thin bar) figure feedback figure correction, aimed to minimize an integral mean-square displacement. The following results are discussed in the paper

- a dynamic I/O model of the beam in the form of "distributed load - distributed displacementïs evaluated.
- a Singular Value Decomposition-type factorization of this infinite-dimension model is evaluated.
- output (displacement) process is shown to be a superposition of "principleßhapes with rapidly decreasing magnitudes;
- sensors and actuators placement is shown to be a problem of optimal discreet (in space) approximation of initial distributed-parameter model, while optimization criteria are addressing minimization of closed-loop integral mean-square error.