Programul de master
Complex Systems

Descrierea disciplinelor din planul de învăţământ

Introduction to Complex Systems

Objectives: formulating the main concepts regarding complex and large scale systems; understanding the current context from a historical, scientific, globalization, industrial and research point of view; introducting specific techniques for the modelling and simulation of complex and large scale systems; defining the main types of control architectures applicable to complex and large scale systems; understanding specific concepts like simulation and computational modelling, methods for the testing and validation of control and monitoring systems; introducing concepts of agent oriented programming languages
Contents: Systems: definition, base concepts, systems thinking, systems engineering, context in research and science; Complexity: definitions, concepts, holism and reductionism, globalization, interconnections, socio-technical aspects, types of complex systems; Complex Adaptive Systems: history, defitions, analysis, design; Dynamics and Chaos: concepts and definitions, significance for complex systems; Evolution: concepts and definitions, significance for complex systems, models of evolution, evolving and adaptive systems design and analysis; Emergence and self-organization: concepts and definitions, significance for complex systems, hierarchies and distribution; Network Theory: definitions, concepts, small world theory, algorithms and analysis; Tools and methods for the study, analysis, modelling, and design of complex systems

Scientific Writing

Objectives: Increasing the ability of writing technical documents and scientific papers as well as the ability to make technical presentations; Presentation of the general structure of technical and scientific documents; Developing the knowledge of writing techniques and methods; Becoming aware of typical errors in the writing of technical documents at all levels (language, coherence, following a storyline, attractivity, presentation mode); Refining the techniques for oral presentation
Contents: What is a scientific article?; An overview of what is right and what is wrong in an article: how to convey the important information; Usual structure of a scientific paper; Style issues. How to write better sentences, paragraphs and sections; Organizing the writing process; Publishing a paper: format, submission, review, revision; Oral presentations techniques; Other necessary skills: English, graphics, editing; Other documents: manuals, technical reports, technical notes; Writing with co-authors (writing management); Ethical issues. Plagiarism.

Evolutionary Computing

Objectives: Riguruous description of the most popular metaheuristics from the domain of Evolutionary Computing; Obtaining the ability to formulate granular optimization problems; Developing the capacity to select the correct metaheuristic method for solving an optimization problem; Implementing the algorithms of evolutionary computing.
Contents: Introduction. Overview on the field of Evolutionary Computing. The Monte-Carlo principle. The evolutionary metaheuristics principle. Convergence conjectures; Local metaheursitics. The Hill Climbing methods (classical and improved with Cauchy compass). The Taboo search (principle, greedy descent algorithm, taboo search method, taboo list, taboo search algorithm, intensification and diversification). Simulated annealing (principle, Kirkpatrick's model of thermal annealing, simulated annealing algorithm). Tunneling (principle, stochastic tunneling, tunneling with penalties, tunneling algorithm). GRASP methods; Global metaheuristics. Genetic Algorithms (biology breviary, genetic operations, inheritors viability, selection for reproduction, selection for survival, general structure of a GA, on the convergence of GA, how to implement a genetic algorithm). Hill climbing by evolutionary strategies (climbing by the steepest ascent, climbing by the next ascent, hill climbing by group of alpinists). Optimization by ant colonies (natural ants, aspects inspired from natural ants, features developed for the artificial ants, basic optimization algorithm by ant colonies, pheromone trail update, systemic ant colony algorithm). Particle swarm optimization (principle, particles dynamical model, selecting the informants, standard PSO algorithm, adaptive PSO algorithm with evolutionary strategy). Fireflies algorithm (principle, dynamical model of fireflies behavior, standard fireflies algorithm). Bats algorithm (principle, dynamical model of bats behavior, standard bats algorithm). Bees algorithm (principle, dynamical and cooperative model of bees behavior, standard bee algorithm). Optimization by harmony search (musical composition and optimization, harmony search model, standard harmony search algorithm).

System-of-Systems Modelling and Analysis

Objectives:This course covers the SoS paradigm, system-of-systems, that dominates through complexity and challengesthe overall domain of systems engineering and this course has as general objective the assimilation of the best methods for description, modeling, simulation and analysis of SoS.; Descriptions of the fundamental characteristics of SoS, of the processes used in SoS engineering, of the modeling, simulation and analysis roles in developing of such systems are given.; Applications of interest in SoS, like critical infrastructures, urban systems and C4ISR (Command, Control, Communications, Computing, Intelligence, Surveillance, and Reconnaissance) are presented.; Discussion of the fundamental principles and concepts of the SoS domain.; Presentation of the five defining characteristics for SoS (Maier's criteria).; Defining the SoS Engineering concept and the composing processes.; Identifying the particular issues in the modeling and simulation of SoS.; Providing representation techniques for SoS, describing SoS architectures and developing methods for SoS.; Description of modeling and simulation techiniques in SoS.; Architectural modeling of net-centered SoS.; Event-based modeling and agent-based modeling.; Bio-inspired SoS modeling.; Presentation of constructive simulations and multi-method for SoS; Illustration of the methods and techniques presented, starting with representative case studies: urban systems, critical infrastructures (interconnected gas and electrical networks), biological systems, medical systems, defense systems, monitoring systems, financial systems.

Contents:Introduction in the System-of-Systems (SoS) paradigm; Methodologies of representation and modeling for SoS; Methodologies for SoS simulation. Multi-method simulation. Simulation tools; Mehotolodies for SoS analysis; Interconnected networks: definitions, metrics and spectral properties, mathematical modeling of multilevel and multiplex networks; Case study: critical infrastructures; Case study: urban systems; Case study: C4ISR systems

Computation for Complex Systems

Objectives:Developing the ability to designt and use algorithms and programs for complex computations, with parallel and distributed characteristics; Understanding the principles for solving large-scale problems; Capacity of choosing an adequate architecture and programming medium for solving an intensive computation problem; Ability to manipulate libraries and languages for parallel and distributed computations
Contents:Parallel and distributed computing architectures; Programming for intensive computation: models, languages, applications; From sequential to parallel algorithms; Message Passing Interface; Coarse grain parallel algorithms; OpenCL: programming for the GPU; Fine grain and synchronous parallel algorithms; Distributed computation on networks; Example: adaptive computation on a random network; Random Boolean Networks

Nonlinear Control

Objectives:Introduction for methods and synthesis techiques for for the control of nonlinear dynamical systems; Highlighting the particularities of control issues for nonlinear dynamical systems; Presentation of control methods for nonlinear dynamical systems; Presentation of state estimation and parameter identification techniques for nonlinear dynamical systems
Contents: Stability of nonlinear systems; Synthesis techniques for nonlinear systems; Observation techniques for nonlinear systems; Output control (internal model control)

Optimization for Big Data

Objectives:Understanding the concepts related to optimization and their use in large scale systems; Familiarity with the current context, from the historic, scientific, globalisation point of view of intrustry and research; Introduction of specific optimization techniques and their use for large scale complex systems; formulation of an optimization problem, identification of properties specific to optimization problems associated with large scale systems (sparsity, convexity, stochastical nature) and choosing an adequate algorithm for their resolution; Iterative optimization algorithms for large scale problems; convergence rates, complexity of an iteration; numerical validation through applications designed during the course; getting aquinted with languages specific to optimization.
Contents:Optimization: definition, concepts, convexity, properties specific to optimization problems associated with large scale systems (sparsity, convexity, stochasticity), research and science context, applications.; Optimization algorithms: 1st and 2nd order algorithms for large scale optimization problems; convergence, numerical complexity.; Decomposition algorithms: primal and dual decomposition; parallel and distributed implementation; analysis of these algorithms, numerical complexity.; Applications:solving linear large scale systems, signal processing, automated learning, optimal control for network-like dynamical systems.; Pachete software: using the optimization toolbox from Matlab and CVX.

Dimension and Complexity Reduction

Objectives:Learn the idea of accurately approximating systems that model real phneomena and (industrial) processes, of high complexity difficult to analyze, simulate or control in their given form. Approximations must be yielded by efficient, low-computartion cost algorithms.; Lectures: understand fundamental concepts forming the basis of model reduction methods used in science and engineering; present the main model reduction techniques for linear systems with their (natural) extensions to complexity and dimension reduction of nonlinear dynamical systems.; Exercise and lab practice: study relevant benchmark examples illustrating methods taught throughout the lectures; solve specific problems using (dedicated software packages in) Matlab.
Contents: Introduction. Signifcant examples.; Preliminaries (I). Matrix linear algebra; SVD. State-space dynamical systems. Geometric properties: comtrollability, observability, Hankel matrix, Markov coefficients. Realization problem, notion of moments, minimality. Linear matrix equations: Sylvester equation, Lyapunov equation in contrinuous and discrete time.; Preliminaries (II). Convolution systems. Associated linear operators. Signal spaces and signal norms. Induced norms. H2 and H∞ norms. Spectrum and singular values. Hankel singula values.; SVD-based methods. Gramians and linear balancing. Model reduction through balanced truncation. BT computation algorithm. Positive-real balancing, stochastic balancing, frequency-weighted balancing. Closed-loop balancing. Hankel-norm approximation. Nonlinear balancing.; Krylov methods. Time-domain moment matching. Iterative methods for ewigenvalue computation. Lanczos algorithms. Convergence. Properties. Arnoldi algorithms. Convergence. Properties. Time-domain moment matching-based model reduction. Two-sided moment matching. Moment matching with preservation of propeties: stability, passivity, structure. Nonlinear moment matching in a nutshell..; Case studies. CD Player. Butterworth filter. DC-DC Cuk converter.

Complex Systems Case Studies

Objectives:formulating the main concepts regarding complex and large scale systems through case studies; using specific techniques for the modelling and simulation of complex and large scale systems through case studies; designing the main types of control architectures applicable to complex and large scale systems through case studies
Contents:Modeling of complex systems.; Illustrative examples.; Nonlinear systems. Linearization.; Systems Biology; Models and enzimatic reactions; Systems with delay.; Aircraft mathematical modelling.; Modeling for unmanned aerial vehicles (UAV): general equations and open-loop dynamics.; Introduction of flight dynamics: aerodynamic control, force and torque coefficients; control surfaces.; Longitudinal static stability, dynamic stability and control. Case study: stability characteristics for the Boeing 747; Plane movement control; Optimal control: linear, quadratic; Optimal control for increased system stability.; System control using: Lyapunov’s theory, PID techniques, optimal control methods, „backstepping” methods; Design and control of a mini quadrotor.; Modeling of complex systems.

Chaos and Fractals

Objectives:Presentation and internalisation of the chaos paradigm.; Understanding and using fractals in control theory.; Basic notions on Discrete dynamical systems; Iterated function systems.; Pompeiu-Hausdorff distance.; Hutchinson operator.; Julia and Mandelbrot Sets, attractors.; Self similarity and dimension, approximating fractal dimension.; Applications to image analysis.

Contents:Introduction and motivation; Basic notions of Calculus, Linear algebra and geometry: metric spaces, contraction theorem, linear maps, contractions in Euclidian spaces.; Discrete dynamical systems: definition, classical examples, attractor. Iterated function systems, Multiple reduction copy machine; Classical fractals: Cantor set, Sierpinski triangle and gasket, Koch curve, Barnsley fern, etc.; Pompeiu-Hausdorff distance, Hutchinson Operator: Pompeiu-Hausdorff distance, the metric space of images, Hutchinson Operator, fractals as attractors of IFS.; Julia Sets and Mandelbrot Set: definitions, basic properties, Dichotomy Theorem, etc.; Basins of attraction associated to the complex Newton method.; Self similarity and Dimension; Methods of approximation for the self similarity dimension: Compass and Box-Counting methods; Applications to Image Analysis

Autonomous Agents

Objectives:Presentation and internalisation of the autonomous agent paradigm.; Analysis and design of multi-agent applications.; Familiarity with the autonomous agent notion in the system engineering context.; Understanding of community limitations, observability and control for a complex multi-agent system.; Analysis and design of the control laws associated to a multi-agent (centralized and distributed). Performance and stability analysis.; Modelling and validation under simulation and experimental setups of the theoretical notions.; Familiarity with tools used for simulation and control of autonomous agents.
Contents:Introduction and motivation; Autonomous robots: introduction, kinematics, modelling (surface, aerial naval autonomous vehicles: common points and differents); Communication limitations (structural, delays, etc.)and their influence on the observation and controllability structure; Control strategies in known environments: centralized and distributed methods; trajectory planning; consensus problem; Control strategies in unknown environments: centralized and distributed methods; exploration and navigation; emergent behavior; Performance and stability analysis of a multi-agent systems under nominal and realist conditions (model variations, disturbances, faults); Case study: analysis of a multi-agent system

Control of Complex Systems

Objectives:Understanding the fundamental principles and methods necessary for the control and its subsequent numerical implementation for complex systems; Using the complex system notions in a large array of industrial applications.; Understanding the control and multi-objective concepts for complex systems as well as understanding the concepts of the model and state-space representation for this class of systems; Solving the issues referring to overall stability and the analysis of complex systems in closed-loop; Using a professional platform (Matlab) in the analysis and synthesiis of complex systems.
Contents:Introduction; Generalized state and rational state representation; Computation of canonical forms for complex systems; Decentralised control; Stabilisation via decentralised controllers; Affine Youla parameterization; Optimal and suboptimal decentralised control; Distrubance attenuation; Singular perturbation analysis; Recovering of optimal global performance; Extensions to general models.