Freie Universität Bozen
Libera Università di Bolzano
Università Liedia de Bulsan

CORSO DI LAUREA IN INGEGNERIA ELETTRONICA E DEI SISTEMI CIBERFISICI
BACHELOR IN ELEKTROTECHNIK UND CYBERPHYSISCHEN SYSTEMEN

Contenuto degli insegnamenti
Inhalt der Lehrveranstaltungen

Primo anno / Erstes Jahr

Mathematical Analysis I (I year, I semester, 9 CFU)

- Elements of set theory, number sets and properties of real numbers.
- Real functions of one real variable: elementary functions, graphs and operations on graphs, composition and inversion.
- Sequences and limits for sequences.
- Limits and continuity of functions.
- Infinite and infinitesimal functions: Landau symbols and rate of convergence.
- Differential calculus and study of a function’s graph.
- Taylor expansions.
- Antiderivatives and integral calculus for functions of one real variable.
- Improper integrals.

Mathematical Analysis II (I year, II semester, 9 CFU)

- Real functions of several real variables, limits, and continuity, partial derivatives and differentiability.
- Elements of differential calculus for functions of several variables: Taylor’s theorem, free and constrained maxima and minima, and critical points.
- Differential calculus for vector functions.
- Curvilinear integrals of scalar functions.
- Curvilinear integrals of vector fields.
- Double integrals.
- Triple integrals.
- Surface integrals. Gauss, Green, and Stokes theorems
- Elements of ordinary differential equations.

Linear Algebra (I year, I semester, 9 CFU)

- Vector spaces and their operations. Spaces R^n. Bases. Scalar product and norm.
- Matrices and their operations. Inverse matrix transposed and conjugate matrix and their properties.
- Linear systems. Matrix form, homogeneous case. Dimension of the solution space, Gauss triangulation method. Linear dependence and independence of vectors.
- Determinant and rank. Recursive definition, Laplace rule, properties. Rank of a matrix. Rouchè-Capelli theorem.
- Linear transformations in R^n. Kernel, image. Eigenvalues and eigenvectors. Isometries and homotheties in R^2.
- Geometry of space. Vector product, mixed product. Cartesian equation of a plan in space. Cartesian and parametric equation of a straight line in space. Skew lines.
- Complex numbers. Properties and operations in the complex field.
- Trigonometric form of complex numbers. N-roots of complex numbers. Equations in a complex variable.
- Representation of linear operators in different bases. Quadratic forms and their diagonalization. LU and QR decomposition, Gram-Schmidt orthogonalization method (also with the use of a software).

Physics I (I year, I semester, 6 CFU)

- Measurement and vectors: units of measurement, dimensions of physical quantities, mathematical operations with vectors.
- Kinematics: mean and instantaneous velocity and acceleration, uniformly accelerated motion.
- Dynamics: Newton's three axioms, work, energy, law of conservation of energy, linear momentum.
- Rotation: angular displacement, mean and instantaneous angular velocity and acceleration, torque, moment of inertia, angular momentum
- Thermodynamics: thermal expansion, kinetic theory of gases, heat, ideal gases, first and second law, circular processes, entropy.

Fundamentals of Programming (I year, 12 CFU)

1. **Module 1: Fundamentals of Programming (I year, I semester, 6 CFU)**
   - Introduction to hardware and software, with computer organisation; data hierarchy; machine languages, assembly languages, high-level programming languages.
   - Introduction to Python: interactive mode, script mode, Jupyter.
   - Introduction to different programming paradigms, focusing on the structured programming paradigm.
   - Structured programming: basic data types, variables, constants, operators and expressions; standard input/output handling; control flow structures; file and error handling.
   - Basic data structures/types of Python: (1) lists, (2) dictionaries, (3) tuples, (4) sets.
   - Subroutines and functions in Python (with/without parameters; with/without return); functions and basic recursion in Python, e.g., some combinatorics.
   - Basics of computational thinking to solve a computational problem and program a resolution in Python and Python-based languages, via physical-computing boards.
2. **Module 2: Fundamentals of Programming II (I year, II semester, 6 CFU)**
   - Introduction
   - Memory management and activation record.
   - Introduction to software development.
   - Software development toolchain.
   - Tools to support modern software development (IDEs; software management tools: DVCS and cloud-based tools).
   - Debugging and software testing (debugging tools; writing safe and secure programs; type checking).

Physics 2 (I year, II semester, 9 CFU) • Electrostatics (charge; coulomb; electric field; electric potential; capacity; dielectrics; permittivity). • Electrical current (Ohm's law; resistance; Joule's effect; power; direct/alternating current; electrical circuits; Kirchhoff's laws). • Magnetostatics (magnetostatic field; magnetic induction; Lorentz's forces; Ampère's laws; magnetic dipoles; magnetic energy). • Dynamic electromagnetism (Faraday-Lenz; self-induction). • Electromagnetic waves (Maxwell's equation; light propagation; polarization of electromagnetic waves). • Photonics: optical phenomena (optics, refraction, interference), introduction to photonic devices. • Introduction to quantum mechanics.
Basics of Electronics (I year, II year, 6 CFU) • Fundamentals of electrical engineering: electrical quantities, concept of bipole and quadripole; ideal and real generators; Kirchhoff's laws. • Adynamic bipoles and circuits: resistive bipoles; Ohm's law; Thevenin's and Norton's models; nodal analysis of circuits, superposition principle. • Bipoles and dynamic circuits: dynamic bipoles; first and second order circuits. • Analysis of sinusoidal circuits: superposition, multi-frequency circuits; Thevenin and Norton models; nodal analysis; power. • Biport: elements; connections; analysis of biport circuits in both adynamic and sinusoidal regimes. • Operational amplifiers: principles; connections; analysis of circuits with operational amplifiers in both adynamic and sinusoidal regimes.

Secondo anno / Zweites Jahr

Algorithms and Programming (II year, I semester, 6 CFU)

- Searching and sorting.
- Analysis of algorithms: correctness and complexity.
- Algorithm techniques: divide and conquer, recurrences.
- Elementary data structures: Pointers, dynamic data structures, linked lists.
- Abstract data types: stacks, queues, priority queues, maps.
- Binary trees, red-black trees, elementary graph algorithms.

Electronic Devices (II year, I semester, 9 CFU)

- Semiconducting materials.
- Semiconductor fabrication and characterization techniques.
- PN junctions and diodes.
- Transistors (MOSFETs; MESFETs; heterojunction transistors)
- Memories (DRAM; SRAM; Flash; resistive).
- Sensors (physical; chemical; biological sensors).
- Photonic devices (LEDs; lasers; photodiodes; solar cells).
- Passive electronic components (antennas; batteries).
- Internet-of-things and sensor networks.

Fundamentals of Systems and Control (II year, I semester, 6 CFU)

- Dynamic response of first and second order systems.
- Stability of linear systems.
- Root-locus stability analysis.
- Dynamic system modelling in frequency domain.
- Frequency-response stability analysis and control design methods.
- Digital control systems (time permitting).
- Computer-aided analysis and design.

Fundamentals of Statistics (II year, I semester, 9 CFU)

- Fundamentals of probability and probability spaces.
- Random variables and probability distributions. Moments of a random variable.
- Functions of a random variable. Bivariate random variables. Sequences of random variables and limit theorems.
- Populations, samples and sampling distributions. Random sampling. Fundamentals of parametric statistical inference.
- Point estimation and interval estimation.
- Fundamentals of hypothesis testing. Tests for the mean and the variance. Chi-squared type tests for contingency tables.
- Estimation methods and distance measures between distributions. Method of moments; Maximum likelihood; Least squares.
- The linear regression model. Assumptions and parameter estimation. Hypothesis testing and confidence intervals for the parameters of the model.
- Model selection, goodness of fit, residuals analysis and diagnostics. Violation of the assumptions and some extensions of the model.

Modern Control (II year, II semester, 9 CFU)

- Modelling and system analysis in state space (dynamic system modelling in time domain and state-space representation).
- Dynamic system response derived from state-space representation and steady-state error.
- Stability in state space.
- Control design in state space (Pole placement design techniques; controllability, observability, full-state observers).
- Optimal control of dynamic systems (Problems with fixed and variable end-points as well as with equality and inequality constraints; maximum principle and Hamilton-Jacobi-Bellmann equation; linear quadratic regulator).
- Understanding of observers in control systems.
- Understanding of optimal state observers and Kalman filters.
- Computer-aided analysis and design using Matlab/Simulink.
- Implementation of controllers and experimental evaluation on real-hardware setups.

Operating Systems and networks (II year, II semester, 12 CFU)

1. **Module 1: Operating and real-time systems (II year, II semester, 6 CFU)**
    - Operating systems principles.
    - Real time systems principles.
    - Multi-programming, multi-tasking.
    - Scheduling and management of processes.
    - Communication and synchronization.
    - Memory management.
2. **Module 2: Networks of electronic devices (II year, II semester, 6 CFU)**
    - Introduction to technology trends (e.g., embedded processors; miniaturized sensors; new materials; ubiquitous computing characteristics and systems).
    - Sensor characteristics and fundamentals (e.g., sensitivity; offset, accuracy, dynamic range, linearity; conditioning; filtering; ADC/DAC).
    - Mobile ad-hoc networks and routing protocols (e.g., flooding; distance vector routing; DSDV Routing; DSR and zone routing).
    - Wireless Communication Technologies (e.g., WLAN/IEEE 802.11; Bluetooth/IEEE 802.15.1, ZigBee/IEEE 802.15.4; RFID; NFC).
    - Wireless sensor networks (e.g., communication architecture, sensor nodes etc.).
    - Machine-to-machine protocols in the cloud, e.g., MQTT and HTTPs.
    - Further data representations and protocols for sensor and control data with a focus on OSC (open sound control) that allows developers to implement a sensor that communicates with 3rd party applications and framework (e.g., MATLAB, Grasshopper, Unity etc.).

Electronic Circuit Design (II year, II semester, 6 CFU)

- Diodes: models, rectifier circuits, linear power supplies, diode-based voltage regulators, limiting and clamping circuits.
- Op Amps: the ideal Op Amp, the inverting and non-inverting configurations, difference amplifiers, integrators and differentiators, Op Amp filters and non-idealities.
- MOSFET and BJT models: physical structure, I-V model, C-V model, parasitic capacitances and resistances, small-signal models, p-channel MOSFET, pnp BJT.
- Transistor amplifiers: basic principles, basic configurations, biasing networks, discrete-circuit and IC amplifiers. Differential amplifiers: differential pair, common-mode rejection, DC offset, differential amplifiers.
- Frequency response: low- and high-frequency responses, approximate analysis methodologies, high-frequency response of MOSFET amplifiers.
- Digital logic circuits: binary representation of information, elements of Boolean algebra, combinatorial logic. CMOS logic circuit topologies, dynamic operation, and power dissipation

Terzo anno / Drittes Jahr

Electronic Systems (III year, I semester, 6 CFU)

- Programmable logic devices (taxonomy; PLC; FPGA: introduction, interconnection resources, I/O reconfigurable blocks, programming; design flow; principles of design, Verilog, system Verilog and VHDL).
- Power supply generation and distribution, heat management, switching mode power supply, linear regulators. Interference between analog and digital and how to avoid them. Signals and bus signal distribution; crosstalk, glitch, debounce. Clock generation and distribution.
- System on chip, system in package, system on module concept and applications. Input and output devices and high-speed interfaces (PCI-Express, LVDS, SerDes, USB3, ETH).
- Sensors in IoT systems.
- RF transmission concepts: WiFi 802.11x, Bluetooth, LoRa, Zigbee, LTE, 3G, 5G, NBIot. Modulations technique, FSK, PSK, OOK, M-QAM.
- New technical trends (IoT systems; neuromorphic and in-memory systems).

Robot Control (III year, I semester, 6 CFU)

- Robot kinematics and dynamics.
- Trajectory planning.
- Motion control.
- Interaction control.
- Vision-based control.
- Remote control.
- Computer-aided simulation and design.

Computer Architecture (III year, I semester, 6 CFU)

- Sequential logic circuits (flip-flop and latches; registers and shift registers; counters; design of sequential circuits from state machines).
- General computer architecture (Von Neumann architecture; CPUs; bus; memory; peripherals)
- Instruction set architecture (CISC vs RISC architecture; instructions: data-movement, control-flow, arithmetic/logic; common ISAs: introduction to x86, ARM, RISC-V; assembly programming).
- CPU architecture (control unit, registers, ALU; fetch-decode-execute cycle; pipelining; super-scalar architecture; branch prediction; out-of-order execution; caches).
- Memory and buses (static vs dynamic memory; serial/parallel buses; synchronous/asynchronous buses; bus arbitration strategies; example of buses: PCI, PCI-Express, USB).
- Other topics (multi-processor and multi-core architectures; introduction to GPUs).

Artificial Intelligence and Machine Learning (III year, I semester, 9 CFU)

- Artificial intelligence and agents.
- Search space exploration.
- Automated planning.
- Data analysis.
- Model selection.
- Supervised learning.
- Unsupervised learning.
- Reinforcement learning.
- Elements of deep learning.

Economics and Management (III year, I semester, 6 CFU)

- The company: objectives and context (basic concepts; classifications of companies; value chain; vision and mission; Porter's generic strategies; strategy tools).
- Essentials of financial accounting (accounting principles; balance sheet and income statement; financial statement preparation; ratio analysis).
- Investment analysis (actualization and capitalization; discounted payback period; net present value; internal rate of return).
- Other economic evaluation analyses (classification of costs; break-even point; make or buy choices).