



ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

ADVANCED COMMUNICATION AND NETWORKING TECHNOLOGIES

Theoretical analysis and performance evaluation of wireless and wired communication systems, network and service design engineering.

Expertise at the University of Bologna covers all aspects of communications and networking, from physical issues, to system design and network architectures.

The research activities cover a wide range of issues: Information theoretic aspects of wireless communications; Indoor and outdoor wireless localization including Ultra wide Band (UWB); Low power optical systems with cavity lasers (VCSEL); Optical system for radio-astronomy applications; Multi-static Radar; Error Correcting Codes; Network protocols design and implementation; Network engineering and performance evaluation; Beyond 5G and 6G Communications; Quantum Communications; Large Intelligent Surfaces; Communications and Technologies.

Besides theoretical research the main focus to date is on the incoming 5G, encompassing all aspects of this emerging technology, in particular: Standardization and regulatory aspects for next generation mobile wireless systems; Cognitive Radio Advanced physical layer techniques (synchronisation, estimation, detection, ...); Radio over Fiber distribution systems; MIMO and Multiple Antenna Systems; Wireless sensor networks and IoT communications; Non-Terrestrial Networks; UAV based communications; Software Defined Networking (SDN) control plane; Network Function Virtualization (NFV); Orchestration architectures for advanced 5G services.

HIGHLIGHTS

European partnerships

The University of Bologna is member of the [5G Infrastructure Association](#) (5G IA), partner of the new Smart Networks and Services (SNS) Joint Undertaking. Moreover the University of Bologna is full member of ETSI and partner of the 3rd Generation Partnership Project (3GPP).

European funded projects

H2020 [5-Alive-5G](#) 5G: A Leadership Vision for Europe (2014-2015)

H2020 [EURO 5G](#): Euro-5G (2015-2017)

H2020 [To-Euro-5G](#): Supporting the European 5G Initiative (2017-2019)

H2020 [EuroCPS](#) European Network of competencies and platforms for Enabling SME from any sector building Innovative CPS products to sustain demand for European manufacturing (2015-2018)

The University of Bologna is the project coordinator of H2020 [Dynasat](#) - Dynamic Spectrum Sharing and Bandwidth-Efficient Techniques for High-Throughput MIMO Satellite Systems (2020-2022).

The University of Bologna awarded a Pre-Commercial Procurement contract [PPDR4Europe](#) - Toward Broadband Emergency Operations: the Broadway Project coordinated by Leonardo



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ARTIFICIAL INTELLIGENCE

A game-changing technology that is bringing transformative change to societies and industries world-wide.

Artificial Intelligence is a very strong and wide field of research at the University of Bologna. It covers both theoretical and technological aspects but also legal, social and economic aspects of AI. Application areas include: manufacturing, agriculture, health, security and forensic, energy, environment, mobility, egovernment, and IoT.

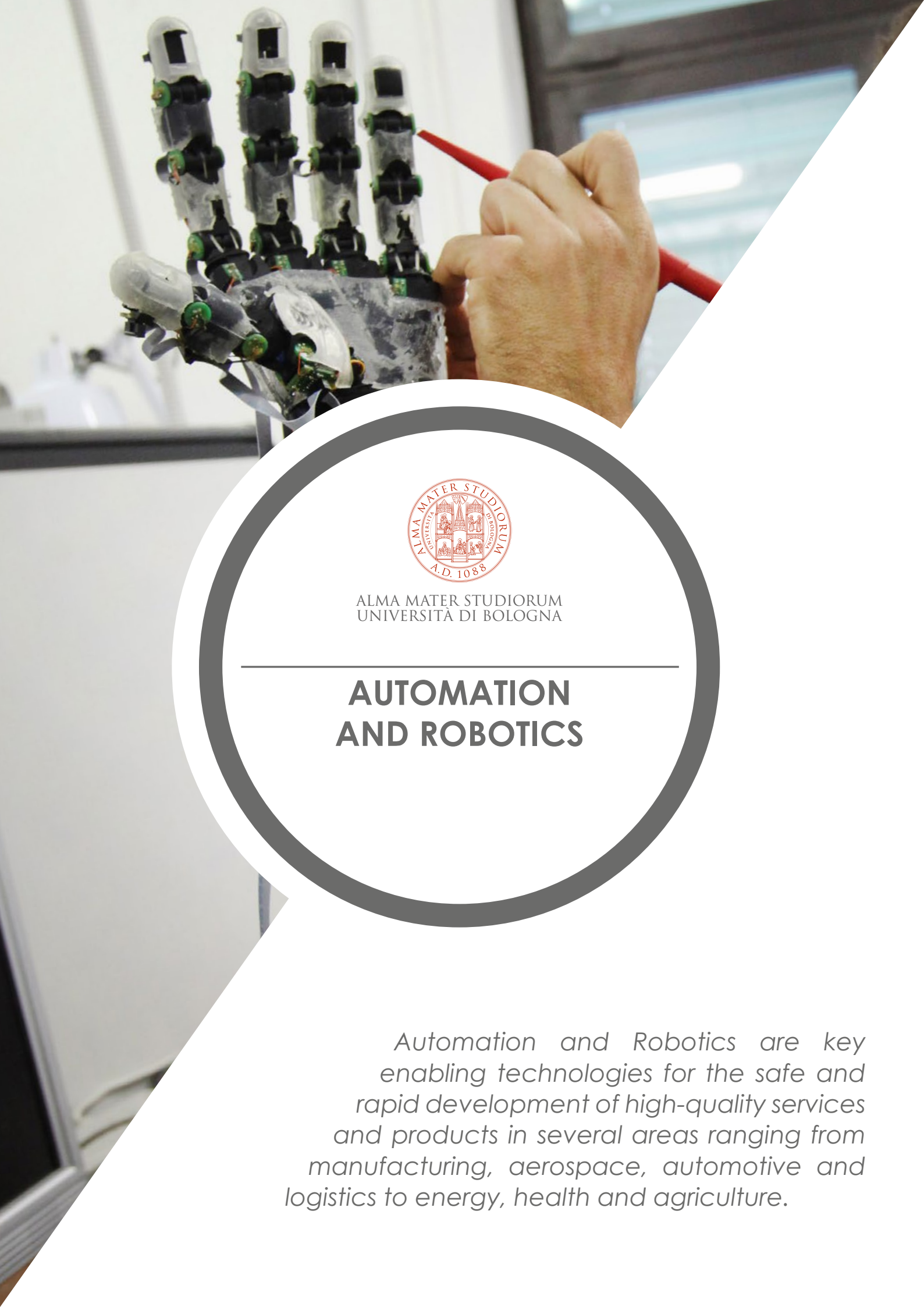
The research activities cover a wide range of issues: Adaptive and self-organising complex systems (simulation tools for “what-if” analysis; information theory and complexity; interaction mechanisms and patterns; swarm robotics and swarm intelligent systems); Deductive, hypothetical and temporal reasoning (reactive event calculus for complex event processing; abduction for hypothesis-based reasoning; knowledge-based reasoning); Hybrid Optimization, decision support systems (machine learning; simulation and optimization; on-line and off-line optimisation under uncertainty; constraint programming tools); Knowledge representation and management (web services orchestrations; data-aware business processes; socio-technical systems); Verification and monitoring (business Processes management; verification and monitoring of process executions; properties of execution traces); Computer vision (video analysis for applications of video surveillance; image analysis and scene understanding; pattern recognition and signal processing); Natural Language processing (machine translation: corpora and methodologies; argumentation mining; deep learning for natural language processing); Human-Machine Interface (brain-computer interfaces; multi-sensory integration; gesture recognition; virtual and augmented reality); Ethical, legal, social and economic aspects of AI.

HIGHLIGHTS

The University of Bologna has recently created a new interdepartmental center on AI: the “**Alma Mater Research Center for Human-Centered Artificial Intelligence**”. [Alma Human AI](#) is an interdisciplinary hub that aims at aggregating and boosting the AI-based research activities that are present in many Departments of the University of Bologna, positioning the University of Bologna in AI research, education, innovation and societal impact at an international level, and approaching AI research from different complementary perspectives. Close collaborations have been built both on national and European level with close connections with the European Association of AI – EurAI, the CLAIRE initiative and with the SuperComputing Applications and Innovation (SCAI) department at CINECA. The University of Bologna is also one of the national laboratory AIIIS – Artificial Intelligence and Intelligent systems at CINI - Interuniversity Consortium for Computer Sciences.

European funded projects

The University of Bologna is the project coordinator of H2020 [StairwAI](#) - Ease the Engagement of Low-Tech users to the AI-on-Demand platform through AI (2021-2023) and is project partner of H2020 [AI4EU](#) - A European AI On Demand Platform and Ecosystem (2019-2021), [HumanE-AI-Net](#) - HumanE AI Network (2020-2023), [TAILOR](#) - Foundations of Trustworthy AI - Integrating Reasoning, Learning and Optimization (2020-2023) and [BonsAPPs](#) - AI-as-a-Service for the Deep Edge (2021-2023). Moreover, the University of Bologna participated in several AI related European projects in different areas (e.g. in H2020 [OPRECOMP](#) and [BISON](#), in FP7 [ePolicy](#), [COLOMBO](#), [DAREED](#) and many others).



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AUTOMATION AND ROBOTICS

Automation and Robotics are key enabling technologies for the safe and rapid development of high-quality services and products in several areas ranging from manufacturing, aerospace, automotive and logistics to energy, health and agriculture.



The University of Bologna is active in the automation and robotics area in many research fields. The activity is spread across many departments, involving electric, electronics, mechanical, system science, biotechnology and psychology areas. The research of the University of Bologna covers a wide range of issues:

- Autonomous and Industrial Robotics (underwater, aerial and agriculture robotics; guidance, navigation and maneuvering; trajectory planning and optimization; visual odometry and SLAM; mobile manipulators; robotic hands and grippers; manipulation of deformable objects)
- Distributed Intelligent Systems and Cooperative Robotics (distributed optimization and control; federated learning; large-scale complex systems; collaborative robots; multi-robot decision and control)
- Advanced Control and Diagnostics in Mechatronics and Automation (advanced nonlinear control; robust control; nonlinear optimal control; system identification and estimation; thermal control for HPC; control of electric drives and power converters; control of smart mechanisms; advanced manufacturing; autonomous vehicles; diagnostics and prognostics of automatic machines)
- AI and Cognition (3D vision; depth estimation; embedded computer vision; object detection and recognition, semantic segmentation; deep learning for computer vision and robotic perception; object perception and representation; affordances and interaction)

HIGHLIGHTS

The University of Bologna is member of the [euRobotics AISBL](#), member of the “AI, Data and Robotics”, one of the European Partnerships in digital, industry and space in Horizon Europe. **Center for research on Complex Automated Systems ([CASY](#))** including a big flight room area equipped with the VICON motion capture system for indoor navigation and rapid prototyping and the **Laboratory of Automation and Robotics ([LAR](#))** with equipment for the development of new robotic prototypes, robotic platforms and several robotics anthropomorphic hands and industrial grippers.

European funded projects coordinated by the University of Bologna

FP7 [AIROBOTS](#) - Innovative aerial service robots for remote inspections by contact (2010-2013)

FP7 [SHERPA](#) - Smart collaboration between Humans and ground-aerial Robots for improving rescuing activities in Alpine environments (2013-2017)

H2020 [AIRBORNE](#) - Aerial Robotic technologies for professional search and rescue (2018-2020)

ERC Starting Grant: [OPT4SMART](#) - Distributed Optimisation Methods for Smart Cyber-Physical Systems- (2015-2021)

[WIRES](#) - Wiring Robotic system for Switchgears (2016-2018)

[REMODEL](#) - Robotic technologies for the Manipulation of complex Deformable Linear objects (2019-2023)



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CLOUD COMPUTING ECOSYSTEM

Infrastructures and ecosystems for advanced cloud computing, including optimizations for cloud continuum (fog), big data management, and latency-sensitive Industry 4.0.

Advanced cloud computing is the primary building block for effective distributed computing ecosystems where applications with industrial requirements can be efficiently built and run, e.g., from I4.0 applications with highly stringent latency and reliability constraints, to elastic and high-demanding big data management services, and to distributed and heterogeneous orchestration of virtualized resources.

The University of Bologna cloud computing research overview:

- Platforms for the integrated monitoring, control, and management of multi-cloud resources (both virtual machine- and container-oriented)
- Edge/fog computing middleware for latency-sensitive and high-reliability applications and for distributed machine learning and distributed AI
- Multi-access Edge Computing (MEC) middleware for 5G/6G-based distributed networking, caching, and processing
- Distributed and interoperable orchestration of resources in the cloud continuum
- Platforms for geographically distributed, federated, and sustainable datacenters, and associated testbeds
- Cloud computing ecosystems for:
 - big data management, in particular for online stream processing
 - I4.0 applications over the industrial Internet
 - smart cities, in particular for citizens' profiling and mobility trends
 - quality-enabled support of 5G mobile services

HIGHLIGHTS

FIBRA UNIBO-UDESC Joint Lab on Big Data for I4.0

The [FIBRA Joint Lab](#) joins public/private efforts in Italy and Brazil to propose innovative models of information management, technology transfer, and ways to develop high value-added ICT companies in cloud computing, in particular for big data support in I4.0.

Federated and Sustainable Cloud Testbeds

The University of Bologna hosts a relatively large private cloud multi-site (Bologna and Cesena) infrastructure, consisting of heterogeneous nodes and Software Defined Networking programmable switches. It is integrated with other public data centers for cloud bursting and large-scale federated testbeds like, for example, EXE.it for low carbon sustainable cloud architectures and Amazon Web Services EC2.

The University of Bologna has contributed to the European research and innovation progress about multi-cloud and cloud continuum paradigms with several projects, starting with "[Mobile Cloud Networking](#)" (2012-2016) and more recently with the large IA "[IoTwin](#)s - Distributed Digital Twins for industrial SMEs: a big-data platform" (2019-2022) and the RIA "[Change2Twin](#) - Create and Harvest Offerings to support Manufacturing SMEs to become Digital Twin Champions" (2020-2023).

In addition, the University of Bologna has participated to several national and regional projects for the exploitation of cloud continuum techniques in digital manufacturing (e.g., funded by MISE and the BI-REX competence center), smart cities (e.g., Ippodamo), and cultural heritage (e.g., Sacher).



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CONVERGING MEDIA & CONTENT, GAMING

Immersive and pervasive solutions for increased personalized user experiences also exploiting gaming technologies.

Media and content convergence enables the interaction with content on any device, anywhere, anytime, and the advancement of “accessibility”. Gaming technologies and mechanics play a crucial role to enhance non-leisure situations and scenarios for training and motivational purposes.



Overview of media & content convergence and gaming research activities within the University of Bologna:

- Augmented and virtual reality
- 3D audio and video
- Virtual worlds
- Interactive/real-time storytelling
- Scholarly digital editions
- e-learning and digital inclusion
- Interactive multimedia technologies with applications
- Multimedia data retrieval and analysis
- Automatic annotation of multimedia data
- Health, transportation, cyber security, digital humanities, fashion, and entertainment systems and applications
- Models for electronic texts in a digital environment
- Digital systems for historical archive finding aids
- Electronic and digital libraries
- Metadata and ontologies in the Semantic Web

HIGHLIGHTS

Laboratory for design & creation of virtual, distributed, and immersive environments: the purpose is to enhance the collaboration between the Department of Computer Science and Engineering and the Department for Life Quality Studies supporting the multidisciplinary among skills in distributed virtual systems, multimedia systems, information systems, simulation and artificial intelligence, sensor networks and image processing and cultures fashion communication. The Laboratory aims to design and implement distributed and immersive virtual environments to experiment with applications of virtual reality and augmented reality.

European funded projects coordinated by the University of Bologna:

H2020 – [DETECT](#) *Detecting Transcultural Identity in European Popular Crime Narrative* (2018-2021)

H2020 – [VOSTARS](#) *Video and Optical See Through Augmented Reality surgical Systems* (2016-2019)



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DATA VALUE CHAIN (INCLUDING BIG DATA AND OPEN DATA)

Methods, approaches and engineering paradigms in analytics and data management.

Data is becoming a new form of asset: data value is increased by delivering new insights and correlations through the combination of individual data chunks. As a result, the ability of collecting, storing, retrieving, monitoring, sharing, analyzing, visualizing, and exploiting large data volumes in an efficient manner is nowadays one of the most important source of value.

The research of the University of Bologna covers a wide range of issues:

- Real-time analysis of massive multimedia streams: exploiting available open-source big data platforms
- Multimedia database management: effective and efficient retrieval of non-conventional data
- Business intelligence: data warehouse design and optimization
- Data mining and knowledge discovery: methods and algorithms for mining knowledge from large data sets
- SmartData: exploiting the information potential of digital data generated through various platforms
- Open data: collection, organization, and publishing of data on the activities and organization of the University for transparency and open government

HIGHLIGHTS

The University of Bologna is member of the Big Data Value/Data, AI and Robotics Association (BDVA/DAIRO), member of the co-programmed European Partnerships on AI, Data and Robotics.

European funded projects

H2020 - [BISON](#) Big Speech data analytics for cONTact centres (2015-2017).

H2020 - [TOREADOR](#) TrustwOrthy model-awARe Analytics Data platform (2016-2018) (UNIBO is a third party of CINI "Big Data" Lab).

Moreover the University of Bologna participated in several BIG DATA related European projects in different domain like Health (e.g. in H2020 [COMPARE](#) and [PROPAG-AGEING](#)), Environment, Energy and Climate Change (e.g. in H2020 [MOSES](#), [ISCAPE](#)) and Smart Cities (e.g. in H2020 [FLEXMETER](#)).

Datalab

A research laboratory where large, massive data collections are managed, searched, monitored and analyzed. Research focuses on tackling complex problems that cannot be solved by means of traditional techniques, due to the inherent nature of data or to the architecture of the system at hand. The lab is equipped with a computer cluster based on Open Source BigData platforms, like Hadoop, Spark, Storm, and Flink and is the site of the Innovation Development Center: a lab, based on Google for Work technology, supported by Injenia (Premier Google Partner in Italy). Collaborations include the BigData lab @CINI and the SuperComputing Applications and Innovation (SCAI) department @CINECA.

Master and PhD programs

Masters in "Data Science", "Big Data Analytics", and "Internet of Things" (Bologna Business School). PhD program in "Data Science and Computation".




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DIGITAL SECURITY

Protecting digital data and preserving user privacy are two of most critical challenges of the 21st century.

The University of Bologna is member of the European cyber security organisation ([ECSO](#)).



The research of the University of Bologna on digital security spans from low-level communication and physical channel protection to mid-level protocols, code and infrastructure security to high-level applications in biometrics, video surveillance and data analysis. IT & Law group studies the many interdisciplinary aspects of law and innovative technologies, with special regards to the impact of privacy, data protection and users' awareness.

The research of the University of Bologna covers a wide range of issues:

- Secure Wireless Communications and Radio spectrum surveillance
- Ultra-wide Bandwidth systems and Wireless sensor networks
- Active and passive radio localization and positioning
- Physical-layer security
- Computer and network security architectures and penetration testing techniques
- Mobile systems and applications security
- Blockchain applications to identity management
- Access control models
- Data protection and Identity management
- Security and privacy in the public and private Cloud
- Location Privacy, Antiprofiling techniques
- Smart Cities and Urban security
- Biometric identification based on Fingerprints and Face
- Computer Vision, Video Surveillance, Event detection
- Search and Analysis of Big Data, Anomalies detection

HIGHLIGHTS

The [Biometric System Laboratory](#) is active at University of Bologna since 1993, and is one of the worldwide leading center for Biometrics research (human identification based on fingerprints, face, iris, etc.). Biometric System Laboratory participated in several EU research projects with a total grant of about 1.5M€ such as FP7 - [FIDELITY](#) - Fast and trustworthy Identity Delivery and check with ePassports leveraging Traveller privacy.

The [Computer Science Department](#) fosters active participation to many networks to create synergies along different dimensions, both at the national and the international level including CINI National Laboratory of Cybersecurity and European Computer Security Organization.

The Interdepartmental Centre for Research in the History, Philosophy and Sociology of Law in Computer Science and Law (CIRSFID) is among the leading excellence centres in Italy and over the years has gained international recognition for its work in computer science and law, as well as in the history, philosophy, and sociology of law. Policy and Regulation of technologies related to privacy, profiling, data protection and identity management is a key topic at CIRSFID.



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HIGH PERFORMANCE COMPUTING

In the digital age, High Performance Computing (HPC) is at the core of major advances and innovation. It dramatically increases the ability to process large amounts of big data and carry out complex computations, which is critical for a large number of scientific or industrial domains.

The University of Bologna is at the forefront of research in high performance computing and participate as a key contributor to the European HPC strategy covering a wide range of issues:

HPC technologies and systems Hardware Development (Computer architecture, parallel programming models and energy optimization; Co-design for added value HPC systems; Fine-grain telemetry systems for large scale green computing systems management); **Software Development** (Big data processing, Cloud, stream processing; Complex Systems, Analysis Systems, Performance Modeling, High Performance Computing Distributed Systems and Algorithms; Energy-efficiency extension for programming libraries and languages, energy and power-aware run-times; **Data center automation** (Algorithms for multiscale data center modelling and management; AI and fog computing solution for automated data center operation and predictive maintenance; System software for holistic monitoring and management of HPC resources).

HPC Applications Using HPC infrastructure, innovative algorithms have been developed in many fields e.g. chemistry, biology, pharmacology, cosmology, high-energy physics and nano-electronics.

HIGHLIGHTS

The University of Bologna is member of the [ETP4HPC Association](#) partner of the EuroHPC Joint Undertaking. **The Energy-Efficient Embedded Systems-EEES Lab** designed, in collaboration with **CINECA** and **E4 engineering s.p.a**, the energy awareness and efficiently support of the [D.A.V.I.D.E. supercomputer](#), the first IBM OpenPOWER system ranked in the Green500 and Top500 list. **The EEES Lab designed, in collaboration with E4 and IBM**, the energy awareness and efficiency support of the Marconi100 supercomputer ranked 9th in the Top500 list of November 2020. The University of Bologna and ETHZ co-developed [PULP](#), the parallel ultra-low power RISC V-based open source hardware platform.

European funded projects

The University of Bologna is member of the consortium to develop Europe's microprocessors for future supercomputer [EPI - European Processor Initiative](#). The University of Bologna participates to H2020 [OPRECOMP](#) - Open transPRECision COMputing (2017-2020), BonsAPPs - AI-as-a-Service for the Deep Edge (2021-2023) and to several FP7 projects (e.g. [PHIDIAS](#) and [VIRTICAL](#)). EEES Lab hosted the **ERC Advanced Grant [MULTIHERMAN](#)** (2012-2018) and awarded a Pre-Commercial Procurement contract (**Phase II and III [PRACE -3IP](#)**) concerning R&D services on Whole System Design for Energy Efficient HPC. Moreover the University of Bologna successfully participated in the EuroHPC calls to promote R&D of supercomputers with European technology with the two funded projects: REGALE - An open architecture to equip next generation HPC applications with exascale capabilities (2021-2023); The European PILOT - Pilot using Independent Local & Open Technologies (2021-2023) and EUPEX - EUROPEAN PILOT FOR EXASCALE (2022-2025)





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INTERNET OF THINGS, CYBER PHYSICAL SYSTEMS AND SMART SYSTEM INTEGRATION

The current move towards pervasive digitalization and connectivity is expected to go on irreversible, until next revolution in civilization models. IoT, CPS and Smart Systems are the key technologies accompanying this process.



The University of Bologna has been **working with the major players** in this field since its start and it is now committed to contribute with its research to the next steps. The IoT industry offers data collection and connectivity solutions solving the interoperability problem at communication level. But more challenges are on the table, including energy efficiency, data reduction, information extraction from big data, security, semantic interoperability, infrastructure-less interaction with the environment.

The University of Bologna teams investigate in the following **horizontal topics** and **related applications**: Self-powering wireless devices and micro-power management; Digital platforms with ultra-low power, parallel, near-sensor processing (e.g. RISC-V architectures); Beyond-IoT architectures for semantic interoperability (e.g. W3C WoT); Beyond-IoT architectures for local and remote interaction; Device Data and Model Integration.

Agriculture, electric mobility, structural and environmental monitoring, long term home assistance are **application domains** of these emerging technologies currently addressed by the University of Bologna teams.

HIGHLIGHTS

The University of Bologna is member of the [ARTEMIS-IA](#), Embedded & Cyber-Physical Systems R&D partners in the Key Digital Technologies Joint Undertaking. The University of Bologna can count on modern laboratories to support the activities in this field, in particular:

- The [SHM LAB](#), the Laboratory of structural health monitoring equipped with prototype structures, data acquisition systems, and structure modeling & simulation platforms;
- The [Joint Lab with STMicroelectronics](#) focused on design with Bipolar-CMOS-DMOS technologies;
- The [MARS LAB](#), the Laboratory of IoT, Web of Things and Interoperability of Embedded Systems

European funded projects

The University of Bologna hosts the ERC [OPT4SMART](#) - Distributed Optimization Methods for Smart Cyber-Physical Networks (2015-2021)

Partner in several H2020 projects:

IoT pilots [SWAMP](#): Smart Water Management Platform (2017-2020)

[EnABLES](#): European Infrastructure Powering the Internet of Things (2018-2021)

ECSEL [NextPerceptios](#): Next generation smart perception sensors and distributed intelligence for proactive human monitoring in health, wellbeing, and automotive systems (2020-2023).

Moreover the University of Bologna successfully participated in the ECSEL calls as linked third party of IUNET: [CONNECT](#) (2017-2020); [AI4DI](#) (2019-2022); [Arrowhead Tools](#) (2019-2022) and [Progressus](#) (2020-2023).



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**MICRO/NANO-ELECTRONICS,
ORGANIC AND LARGE
AREA ELECTRONICS**

Embedded systems featuring innovative microelectronics components based on next-generation devices, highly reliable systems, development of new technologies for energy efficiency, microcontrollers and sensors for biomedical applications and environmental monitoring.

The research of the University of Bologna covers a wide range of issues:

Modeling & Characterization

- Modelling and simulation aspects of micro/nano-electronic devices: simulation based on semiclassical microscopic transport models of nanoelectronic devices and quantum numerical simulation of nanoelectronic devices
- Organic/inorganic semiconducting materials and devices with applications on wearable devices, realized on non-conventional substrates
- Design of energy harvesting circuits and systems, with a special focus on micro-/nano-power scenarios
- Design of ultra-low power electronic systems
- Applications of piezoelectric transducers for real-time monitoring of physical properties of materials and objects

Electronic design

- Innovative systems in health/energy/environmental monitoring, in industrial manufacturing/production and in food/agriculture
- Low power electronics and sensor to fit many application scenarios: design of high-accuracy and low-noise circuit interfaces for several types of sensors; design and characterization of capacitive sensors including custom implementations; design of integrated circuits and MEMS and energy autonomous sensor nodes for IoT; RFID systems; smart metering for smart grid/buildings applications and biosensors and lab-on-a-chip devices

HIGHLIGHTS

The University of Bologna is member of the [AENEAS](#) - Association for European NanoElectronics Activities (Nanoelectronics R&D partners in the [ECSEL JU](#)).

At national level, it is member of [IUNET](#) - Inter-University Consortium for Nanoelectronics and of the Mirror Group [ECSEL ITALIA](#).

The inter-department research center [ARCES](#) focused on Nanoelectronics, Microsystems and IoT hosts the **ARCES-ST joint Lab**, the industry-academia joint laboratory with STMicroelectronics Italia.

European funded projects

H2020 FLAG-ERA [CONVERGENCE](#) - *Frictionless Energy Efficient Convergent Wearables for Healthcare and Lifestyle Applications* (2017-2020)

Partner of the following H2020 ECSEL projects:

[R2POWER300](#) - *Preparing R2 extension to 300mm for BCD Smart Power* (2015-2018)

[R3-PowerUP](#) - *300mm Pilot Line for Smart Power and Power Discretes* (2017-2021)

[WInSiC4AP](#) - *Wide band gap Innovative SiC for Advanced Power* (2017-2020)

[CONNECT](#) - *Innovative smart components, modules and appliances for a truly connected, efficient and secure smart grid* (2017-2020)

REACTION - *first and euRoPEAn siC eigTh Inches piLOt liNe* (2018-2022)

AI4DI (2019-2022)

iRel40 - *Intelligent Reliability 4.0* (2020-2023)



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OPERATIONS RESEARCH

Efficient decision making based on quantitative results is essential for success in business and management.

Project planning, network optimization, facility location, routing, supply chain management, scheduling, among others, are real problems tackled by Operation Research. Industrial sectors that benefit from Operation Research range from airlines (scheduling, tariff policy), to hospitals (scheduling), to electric utilities (production, trading) and logistics (route scheduling).



The University of Bologna is active in the Operations Research area developing innovative models and algorithms for the optimization of hard decision and planning problems in several application domains:

- Routing and logistics (Variants of traveling salesman and vehicle routing problems; Waste management; Demand analysis and network design for freight transportation; Drone and autonomous vehicle routing)
- Cutting and Packing (Large-size knapsack problems; Non-linear variants of knapsack problems; Two and three-dimensional bin packing problems)
- Energy Production and Distribution (Plant location for wind farms; Design of district heating and cooling networks; Relocation operations in electric car-sharing)
- Railways and Airlines (Crew and resource scheduling problems (Rail, Airline, Integrated and Robust planning); Timetabling and resource optimization (i.e. Rolling stock circulation, platforming); Online train rescheduling and disruption management; Rail freight transportation; Energy consumption optimization)
- Exact and heuristic algorithms for Integer Linear and Non-Linear Programs (Heuristic and matheuristics for Integer Linear Programs; Heuristics for multi-objective MINLPs; Decomposition techniques; Exact and heuristic algorithms for bilevel programming)
- Optimization on graphs (Exact and approximation algorithms for clustering, connectivity and node detection)
- Healthcare applications (Resource allocation and scheduling; Robust planning)

HIGHLIGHTS

The research activity at [the Computer Science department](#) is active in design methodologies, modeling techniques and solving strategies for decision support and optimization systems.

Laboratory on Optimization of Operations Management (LOOM): development of advanced models and algorithms for the optimization of freight distribution logistics, industrial packing and loading and waste logistics.

Several state-of-the-art instruments and advanced laboratories are available within **the Center for Industrial Research on Information and Communication Technologies (CIRI ICT)** of the University of Bologna in support of research activities on sustainable innovation.



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SOFTWARE ENGINEERING, PROGRAMMING LANGUAGES AND FORMAL METHODS

Research on programming languages and formal methods exploits mathematical techniques for designing, realizing and verifying complex software systems.

Software engineering, programming languages and formal methods are very strong and wide fields of research at the University of Bologna which cover both theoretical and technological aspects. The research of the University of Bologna strongly covers theoretical and technological aspects of software engineering, programming languages and formal methods in many different application areas: manufacturing, health, security and forensic, mobility, social platforms, software platforms, IoT.

Selected research topics are the following:

- Agent-oriented methodologies and tools
- Application Program Interfaces ecosystems
- Constraint Programming:
 - Application to Software Defined Networks
 - Hybrid optimization
 - Portfolio Solvers
- High level languages for IoT:
 - Logic based languages and technologies
 - Microservice languages
- Hybrid programming languages
- Logic-based languages for:
 - AI applications
 - Knowledge representation and reasoning
 - Verification and monitoring of software systems
- Multi-paradigm programming models
- Multi-platform languages and tools
- Probabilistic computing: models and languages
- Proof techniques for the analysis of systems and languages
- Reversible computing and reversible debugging
- Semantic models for quantum programming languages
- Service oriented computing and microservices

HIGHLIGHTS

The University of Bologna and INRIA, the main French national institute on research in ICT, have created a **joint research team on languages and semantic foundations for distributed systems**. Innovative methods and techniques are developed for verifying important computational properties of the systems, as well as for proposing linguistic constructs for them.

European funded projects

The Department of Computer Science and Engineering hosts the ERC Consolidator Grant DIAPASoN – Differential Program Semantics (2019-2024). The University of Bologna coordinated the European FP7 project [CERCO](#) - *Certified Complexity* (2010-2013) and participated in several European projects, e.g. FP7 - [ENVISAGE](#) *Engineering Virtualized Services* (2013-2016) and FP7 – [HATS](#) *Highly Adaptable and Trustworthy Software using Formal Models* (2009-2013).