Project Area: Future Internet

Revision: June 2018

Participants

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Effort

	N.	Impegno totale su AP (FTE)	Impegno medio su AP (mesi annui/persona)
Dirigenti di ricerca	5	3	7.2
Primi ricercatori	8	3.79	5.7
Ricercatori	33	23.8	8.7
Tecnici	2	0.5	3
TDET	18 (ric) + 2 (tec)	15.9 (ric) + 1.5 (tec)	10.6 (ric) + 9 (tec)
PhD/Research Fellows	9	7.75	10.3
TOTAL	**77**	**56.24**	**8.8**

Research Themes and Topics

- 3 research themes
  - **NGI**: Next Generation Internet
    - NGI communication technologies beyond 5G and network measurements (IEIIT, ISTI, IIT)
    - NGI network paradigms (IIT)
    - IoT and WSN in NGI and NGI industrial networks (ISTI, IIT, IMATI, IEIIT)
  - **HPC**: Distributed Parallel and High Performance Computing
    - Cloud Computing (IMATI, INM, ISTI, ICAR)
    - Edge Computing (IIT, IMATI, ISTI)
    - High Performance Computing (IIT, IMATI, ISTI, ICAR)
  - **SW**: Software Engineering
    - Formal Engineering of Cyber-Physical Systems (ISTI)
    - End user development of internet of things applications (ISTI)
    - Agents and self-adaptive systems (ICAR)
    - Testing of software systems and services (ISTI, IASI)
    - Monitoring and analysis of software architecture and Smart Environment (ISTI)
    - Software Verification via Constraint Solving (IASI)
    - Modelling and Verification of Business Processes (IASI)

NEXT GENERATION INTERNET

NGI communication technologies beyond 5G and network measurements
(IEIIT, ISTI, IIT)

Design and optimization of 5G MIMO

Key Challenges

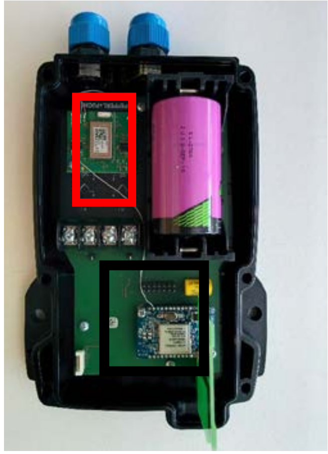
- Development of advanced algorithms for wireless massive MIMO systems.
- Design of application-dependent codes and decoders for wireless and optical communications and memory storage.
- Enabling technologies for future emerging dense wireless IoT networks including advanced algorithms for distributed sensing and energy-aware management.

Approaches

- Theoretical analysis and practical development of optimal and suboptimal receivers for MIMO systems.
- Analysis of wireless systems coexistence, connectivity and communication strategy in heterogeneous networks, user mobility characterization, orchestration of network slices in 5G.

Key Results

- Development of cooperative and cognitive systems and ultra-low power designs.
- Energy-efficient transmissions for industrial wireless cloud network (WCN) for critical monitoring.



Laboratories

- **WaveLAB**, Milano, Wave-based technology testing Laboratory from MHz to THz.
- **WiLAB**, Bologna, Wireless Communication Laboratory.

WCS - Wireless Communication Systems

Design of mobile and vehicular networks

Key Challenges

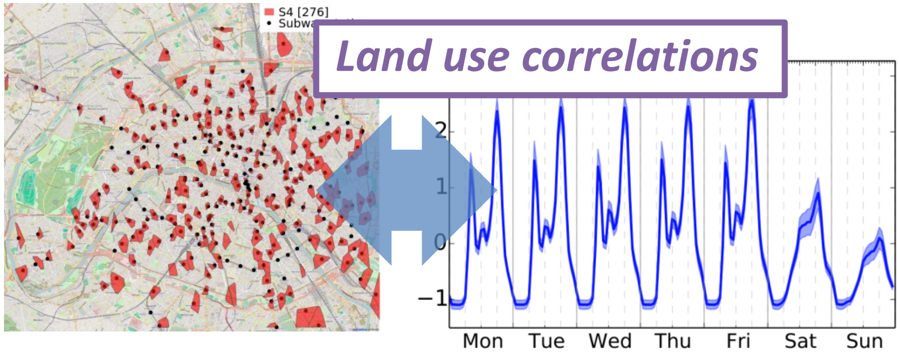
- Development of new architectures for vehicle-to-vehicle and vehicle-to-infrastructure communications.
- Analysis of the space-time dynamics of the demands for mobile services in urban areas.
- Connected vehicle safety systems that rely on vehicle-to-vehicle communication for obtaining real-time situational awareness and detecting possible hazards.

Approaches

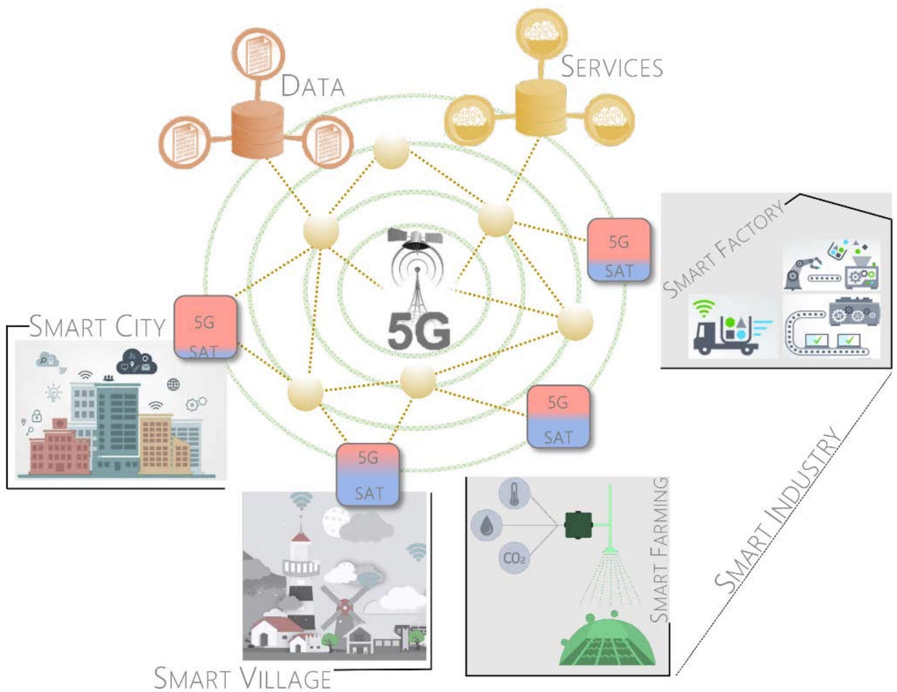
- Design of full-duplexing approaches to increase capacity and reliability in vehicular network infrastructures.
- Development of models for prediction of dynamics of the demands for mobile services in urban areas, using large-scale real-world datasets.
- Realistic simulations of vehicular networks.

Key Results

- Testbeds of connected vehicles based on IEEE 802.11p/ITS-G5 standards.
- Analysis of direct vehicle connectivity at large scales.
- Analysis of network traffic offloading and multi-RAT in automotive services.

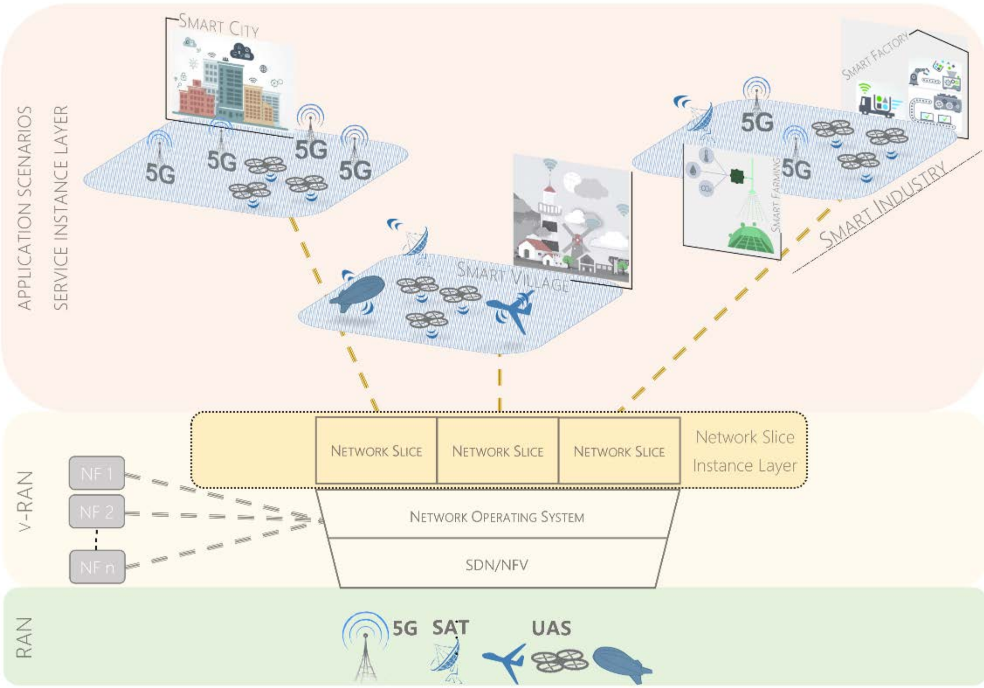


5G & Space Information Networks



Key Challenges

- Breaking of cell-centric architecture with devices managing in parallel multiple connections to multiple access points, relay nodes or other end-devices, even based on heterogeneous radio access technologies.
- Softwarization and re-programmability of network functions at different levels, including the same MAC/PHY functionalities.
- Network intelligence and dynamic reconfigurations of the systems, for dealing with highly variable service requirements and handling large quantities of low data communications, enabled by M2M applications.



Approaches

- Theoretical analysis.
- Simulations.
- Testing of prototype systems.

Key Results

- Robust multihomed and multipath communication protocols for real-time and streaming applications.
- Flow control of machine type traffic in massive scenarios.

Wireless Networks Lab

Internet measurement

Key challenges:

- Develop distributed tools to **map the Internet structure** as precisely as possible
  - Coping with poor coverage/representativeness of typical approaches based only on monitoring from the core
  - Improve the amount of data sources available directly from Internet players

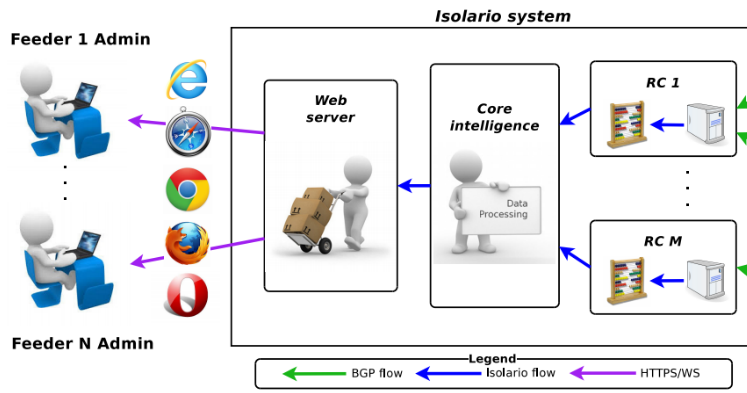
Approaches

CROWDSOURCING techniques

- Involve end users to take sporadic and low power measurements from their devices

OPERATOR value proposition (do-ut-des)

- Trade information about their network structure for real-time and historical services



Key Results

- Better coverage of Internet structure
  - Isolario is the BGP route collecting project with the largest amount of routing tables
- Novel operators services
  - Real-time services for operators
  - Alerting systems
  - Historical services
  - Daily reports

Real-time services

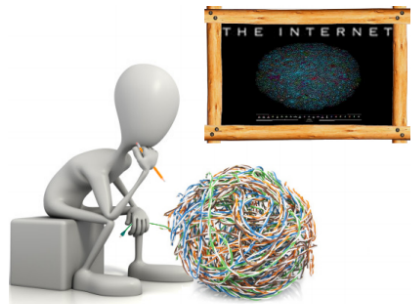
Something is happening
How is my RIB(s) evolving?
How is my reachability affected?

Alerting System

Something is happening NOW!
Check real-time services!
Do something! (if needed)

Daily report

Did something happen yesterday?
Check historic services!
Do something! (if needed)



NEXT GENERATION INTERNET

NGI paradigms (IIT)

Key challenges:

- Internet **expanding at its edges** much more than in the core
- Edge dominated by users' personal devices
- **How to make the Internet a human-centric network?**

Approaches

DEVICE-CENTRIC network organisation

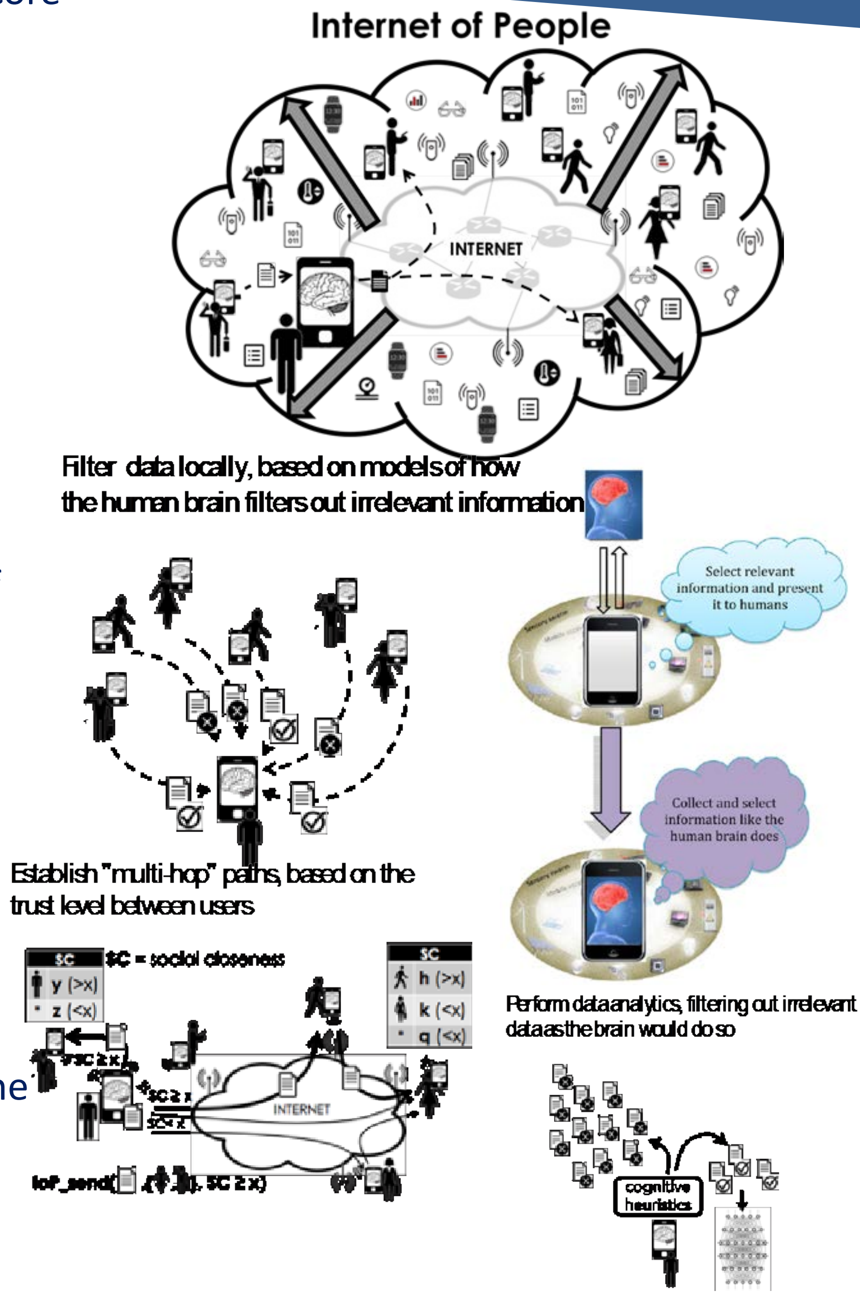
- Bottom-line idea: most information is generated at the edge of the network, and interesting for users nearby
- Give edge nodes much more freedom (and responsibilities) to organize the network around them

HUMAN-CENTRIC INTERNET PROTOCOLS

- **Bottom-line idea**: users' personal devices are proxies of the their (human) users in the Next Generation Internet
- Therefore
  - Identify **models of human individual and social behavior**
    - e.g., to filter data, share resources, establish trust
  - **Embed the very same models** into Internet protocols

Key Results

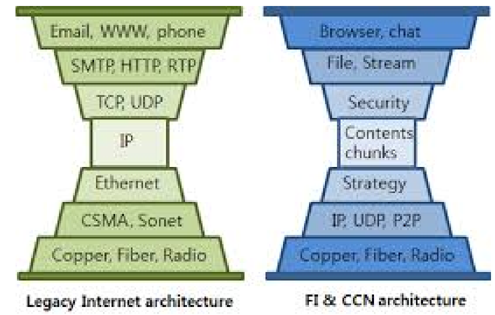
- Initial results on applying this concept
  - Social-based data dissemination
  - Cognitive-based data filtering
- Establishment of the main IoP concept in the international research community
- Contributing to shape the research agenda



Information Centric Networking (ICN)

Key challenges:

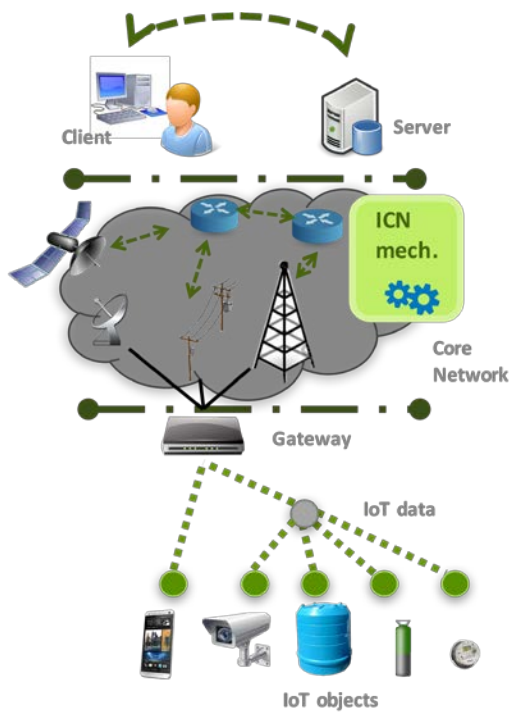
- Internet is more and more a data-centric network
  - Thus, **ICN** approaches have been proposed
- How to use them **at the edge** of the network?
  - In presence of **mobile** devices



Approaches

ICN mobile architectures

- Take standard ICN architecture designed for the fixed Internet
- "Tweak" it to work well also in presence of mobile devices at the edge
  - Including IoT networks of tiny devices



Key Results

- Support realization of an end-to-end ICN networking architecture **including also mobile elements**
- Open up **IoT** applications to the ICN paradigm

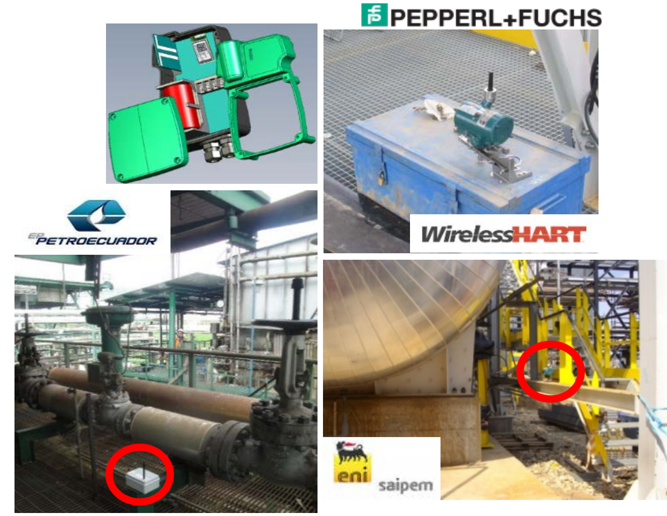
NEXT GENERATION INTERNET

IoT and WSN in NGI and NGI industrial networks (ISTI, IIT, IMATI, IEIIT)

Industrial IoT

Key challenges:

- Propose new architectures and designs for next generation **networks, sensors and cyber physical systems** for Industry 4.0.
- Next Generation Internet solutions for the smart factory as technology enabler for robot-assisted manufacturing in shared workplaces.



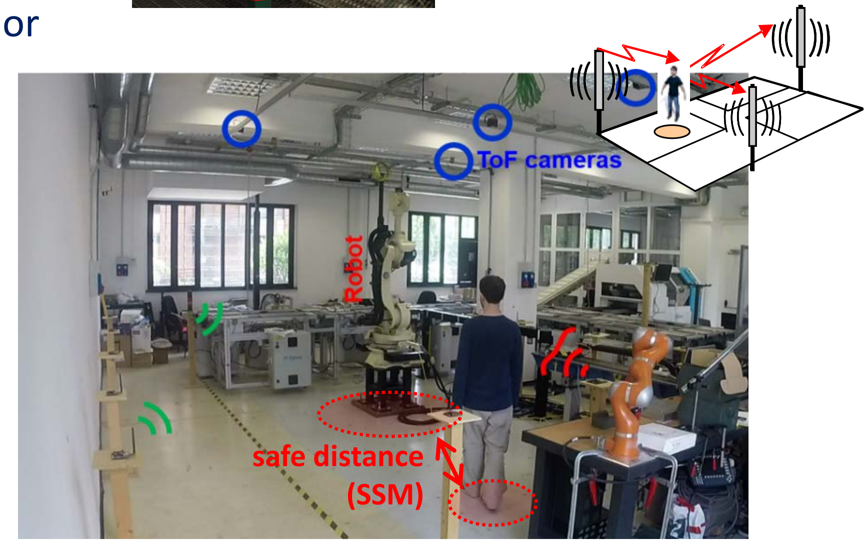
Approaches

NETWORKS

- Planning, verification and optimization.
- Industrial IoT system design for smart industries.
- Distributed control and ultra-low-latency MIMO communication systems.

SENSORS and SYSTEMS

- Passive worker recognition in collaborative workplaces.
- RF-based and computer vision: worker activity/behavior detection and human-machine interface.

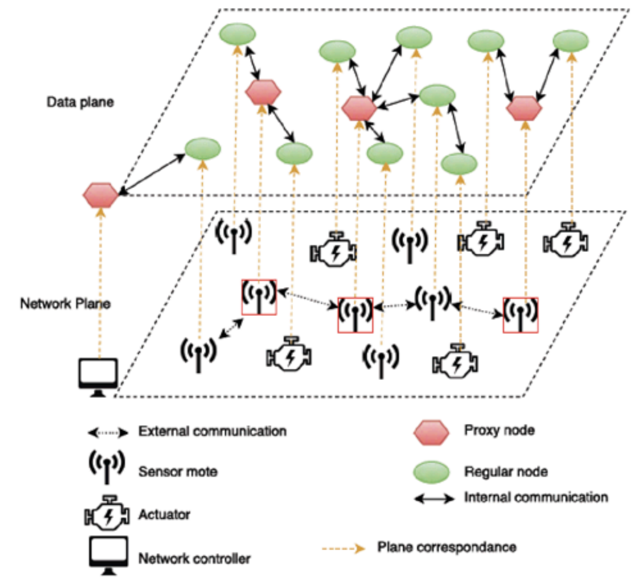


Key Results

- Development of distributed architectures and algorithms for dense wireless cloud network platforms.
- Environmental recognition and vision capabilities from the analysis of high-frequency radio signals.

Key challenges:

- Develop **distributed data management** architectures and protocols for **wireless Industry 4.0** environments
    - Guaranteeing typical industrial constraints (e.g., real-time delivery, energy efficiency)
    - Optimising resources (e.g., energy of sensor nodes)



Approaches

DISTRIBUTED **DATA MANAGEMENT**

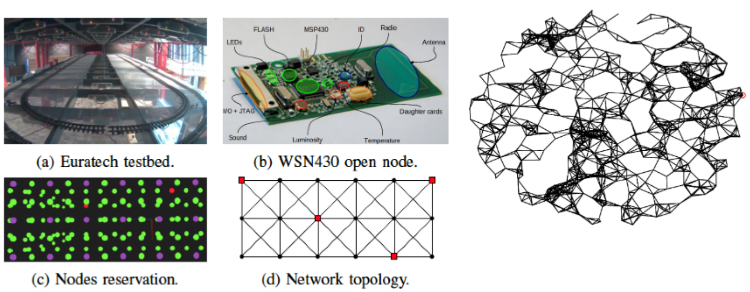
- Use all nodes in the network as potential location to store and serve data to the rest of the nodes
- Optimise the choice of nodes based on data generation and request patterns
    - Taking into account heterogeneity of nodes' resources

ADATIVE MECHANISMS

- Dynamically reconfigure data management configuration w/o centralized control in case of environmental changes (e.g., nodes failures)

Key Results

- Data management algorithms outperforming existing solutions
- Pilot developments in industrial sites (e.g., Tekniker Spain)
- Experimental implementation in medium-scale IoT testbeds



(a) Euratech testbed. (b) WSN430 open node. (c) Nodes reservation. (d) Network topology.

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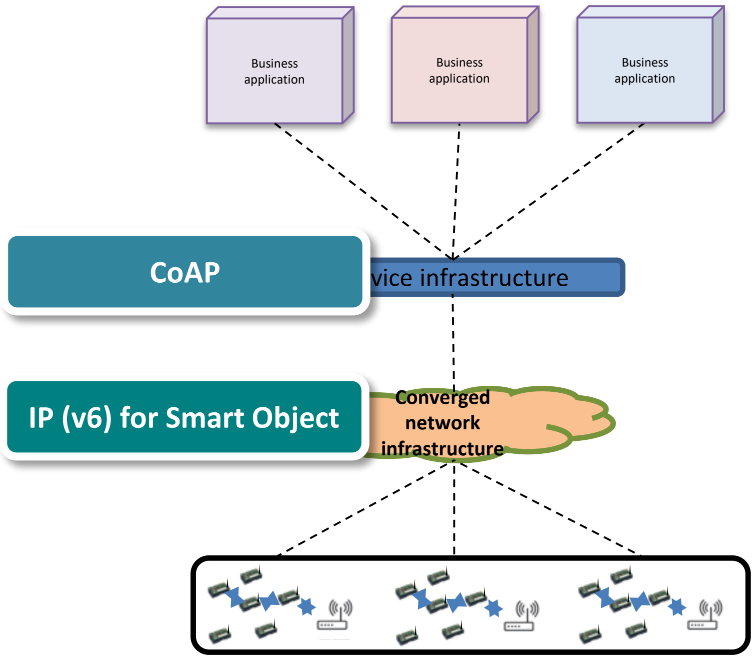
Protocol and Service Architectures for the Internet of Things

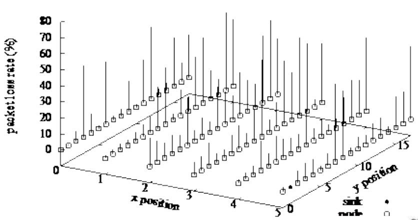
Key challenges:

- Develop network-layer protocols to provide ultra-reliable communications
- Develop resource sharing frameworks to improve QoS of heterogenous IoT applications that are concurrently running on the same infrastructure
- Interoperability is fundamental for IoT success



Approaches

- More efficient mechanisms for route discovery and topology repair, especially under mobility are needed to reduce communication losses
- Congestion control algorithms are needed to improve scalability
- IoT gateways should provide application brokering functionalities to regulating the access to IoT resources and to avoid unfair usage of network bandwidth



Key Results

- Improved reliability of RPL routing protocol
- Rate-based congestion control algorithms for COAP
- Prototype of an enhanced Internet-based protocol stack for LLLNs

Ubiquitous Internet

Key challenges:

- Propose new architectures and designs next generation **WSNs for monitoring purposes** in naval, home/office, industry, ambient and indoor environments
- Next Generation WSNs with heterogeneous sensors, which use different communication protocols and data formats.

Approaches

- Design architecture to increase capacity and reliability in WSNs.
- Simulations in WSN environment
- Planning, verification and optimization of the monitoring systems.

Key Results

- Development of distributed architectures and algorithms for long-term monitoring purposes.
- Context awareness applications
- Environmental recognition from the analysis of WSNs signals.
- Development of distributed algorithm able to automatically detect behavioral changes without explicit activity modeling

Asset tracking

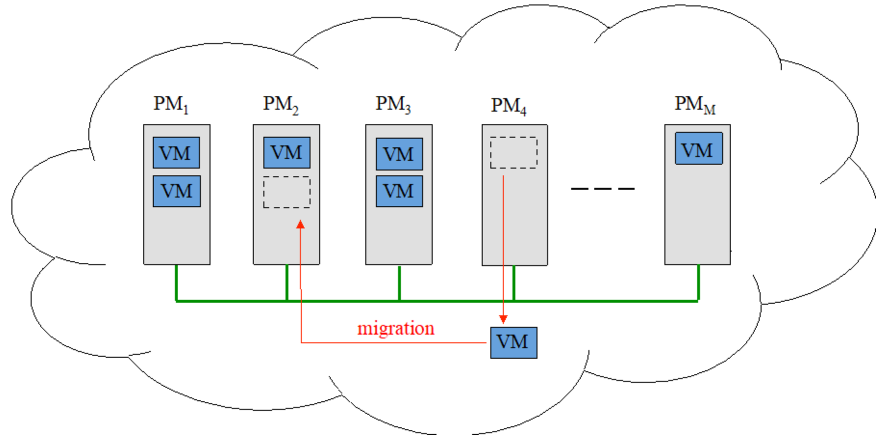
Production Monitoring

Safety and security monitoring

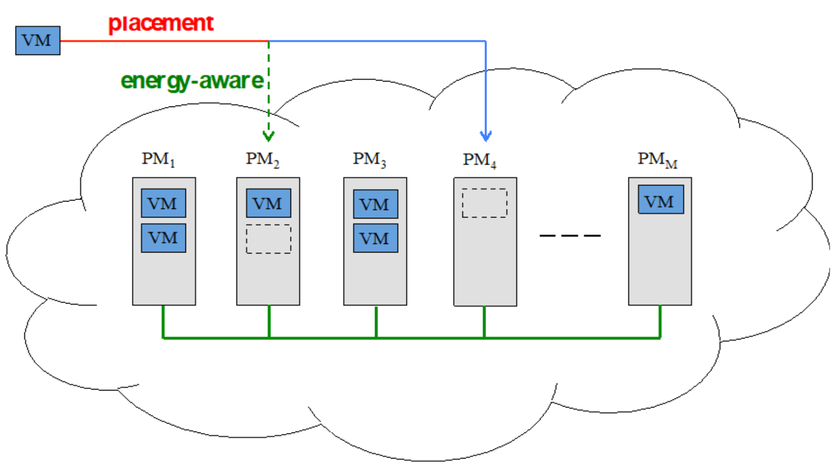
HPC: DISTRIBUTED PARALLEL AND HIGH PERFORMANCE COMPUTING

Energy-aware consolidation and placement of virtual machines

- ***Key challenges***: reduce the energy consumption of Internet-scale datacenters while maintain suitable degree of quality, security, and dependability.
- ***Approach***: model predictive control to exploit future information together with efficient optimization techniques.
- ***Key results***: placement and consolidation strategies to migrate and deploy virtual machines over servers.



VM is migrated to offload the server, which can be put in sleep to save energy



The requested VM initially placed in order to avoid overloading the servers and to save energy

Computing architectures and HPC

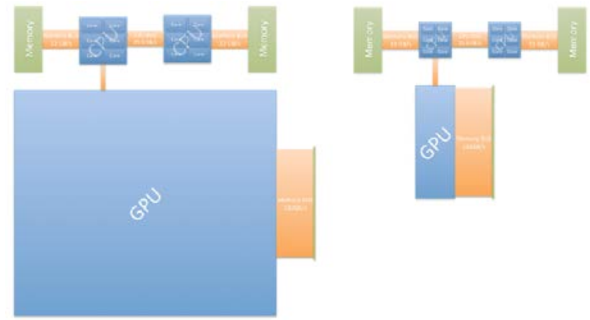
Complex Systems Lab

INM/CNR ISTITUTO DI INGEGNERIA DEL MARE

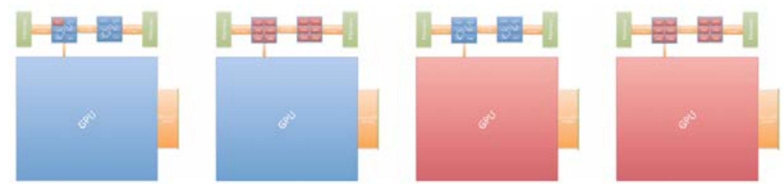
Software design for complex heterogeneous HPC systems

Key challenges

Nowadays even a simple computing node is a complex system including multicore CPU and coprocessor such as GPU. The absolute and relative performance of each component (its area) may change e.g. if we consider single precision on the left, double precision on the right. Moreover available memory and its bandwidth are heterogeneous and with a different access cost.



Different programming paradigms have been proposed to develop software that is able to exploit this kind of complex system. From left to right: single core—sequential application; up to 12 cores—MPI and OpenMP; GPU cores—CUDA; CPU and GPU cores—OpenCL and OpenACC.



However there is not a wining paradigm and the design of algorithm and software remains an heuristic that depends on many aspects.

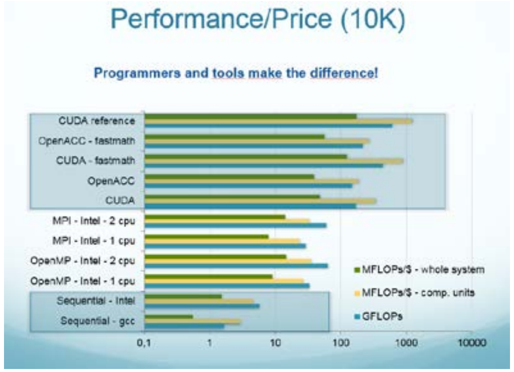
The lesson is that the free lunch is over and applications will increasingly need to be concurrent if they want to fully exploit continuing exponential CPU and GPU throughput gains and their combined effect

Software design for complex heterogeneous HPC systems

Approach

To obtain suitable results in real world applications it is necessary to take into account a number of elements including:

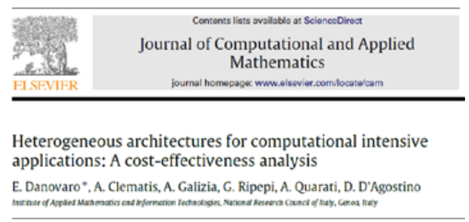
- Understanding of the problem of its possible modeling and computational solutions and of their requirements;
- Mapping of algorithms to architectures, considering aspects such as programming model, arithmetic requirements, data movement and others;
- Selecting the appropriate compiling tool able to exploit available architectural features (e.g. vectorization);
- Selecting the appropriate parallel library and or domain oriented library;
- Close the "Ninja Gap" that is the performance gap between mostly-numerical code written by experts compared to the same code written in a traditional style by lesser programmers



Software design for complex heterogeneous HPC systems

Key results

- A strong body of knowledge and expertise mastering aspects related with architectures, programming paradigm, domain oriented libraries, algorithm design and applied in different fields including image processing, 3D data analysis, bio-info applications, numerical libraries evaluation and others
- Providing consulting and high level training to the community PhD. Course on Programming Complex High Performance Computing Systems, System Engineering Program, DIBRIS University of Genova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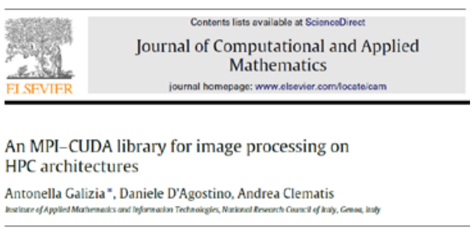
Heterogeneous architectures for computational intensive applications: A cost-effectiveness analysis

E. Danovaro*, A. Clematis, A. Galizia, G. Ripepi, A. Quarati, D. D'Agostino

Institute of Applied Mathematics and Information Technologies, National Research Council of Italy, Genoa, Italy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An MPI–CUDA library for image processing on HPC architectures

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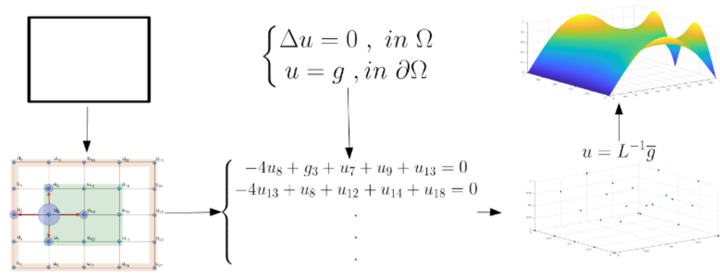


Key challenge

- the amount of data sensed by IoT devices, e.g. in Industry 4.0 plants or large-scale scientific experiments, are beyond network capabilities.
- A new and holistic approach for managing available resources for data processing and transfer is necessary

Approach

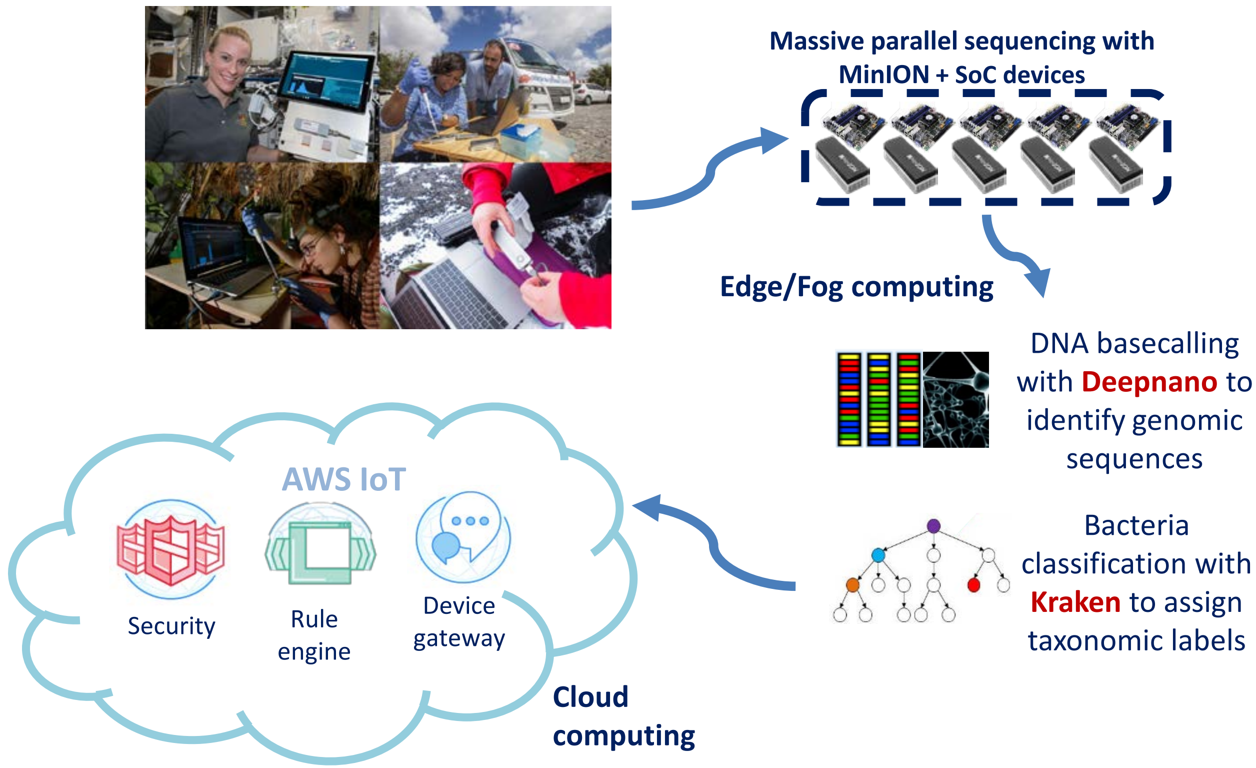
- The flexible use of distributed computing paradigm for an effective scheduling of data processing tasks
- The use of low-power architectures for moving most of the computation close to the data sources
- The use of Cloud computing for data aggregation and knowledge extraction

Key results

The prototype of an IoT platform for monitoring the microbioma on the field.

Low-power devices can be used to analyse sequencing locally data in real-time.

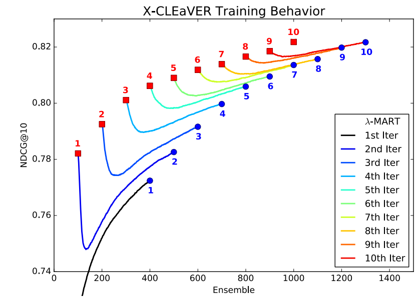
Cloud IoT platforms can be used to trigger alarms or to identify set points using data analytics techniques.

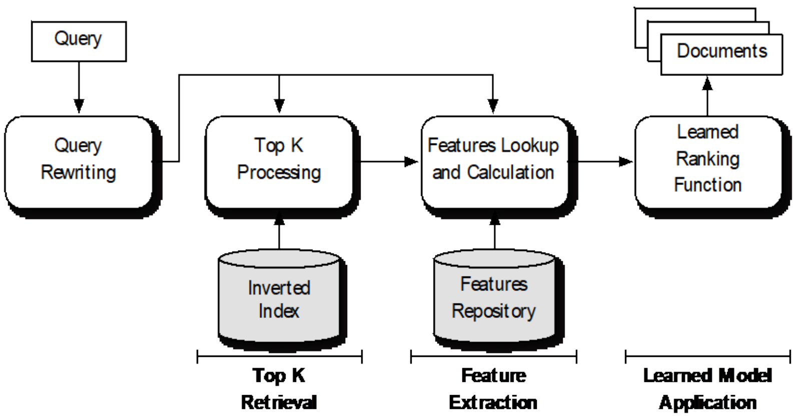


Low-Power Portable Devices for Metagenomics Analysis: Fog Computing Makes Bioinformatics Ready for the Internet of Things, Future Generation Computer Systems, 2018

Key challenges:

Future information systems must scale far larger of existing ones in order to provide in near real-time accurate answers to complex queries by possibly using a limited amount of computational resources and energy



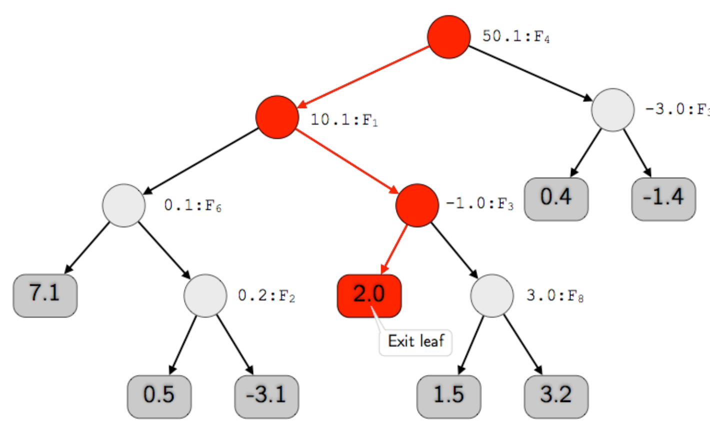


Approaches

We gather large volumes of direct or indirect evidence of relationships of interest, and design scalable algorithms to extract accurate and efficient models to: rank results of queries, predict the evolution of complex phenomena, provide context-aware personalized recommendations, semantically enrich heterogeneous (spatio-temporal) data

Key Results

- Novel scalable algorithms reducing the training time and the latencies of machine learnt models
- Predictors of query/job latencies to feed adaptive scheduling strategies enhancing throughput and reducing energy consumption
- Space- and time- optimal index compression and query processing algorithms



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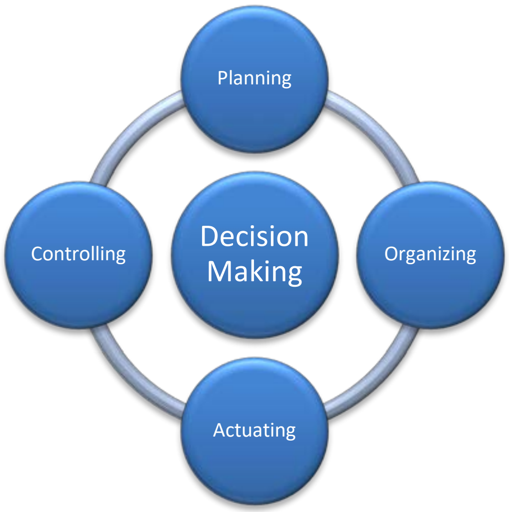
HPC Lab

Clouds, Federations, Edge Computing

Key challenges:

System and Application scalability, efficient management mechanisms, continuous exploitation and control of resources and services on **Future Clouds**: global, hyper-connected systems that span over the globe and exploit the whole device hierarchy: HPC, Data centers, edge and embedded systems.

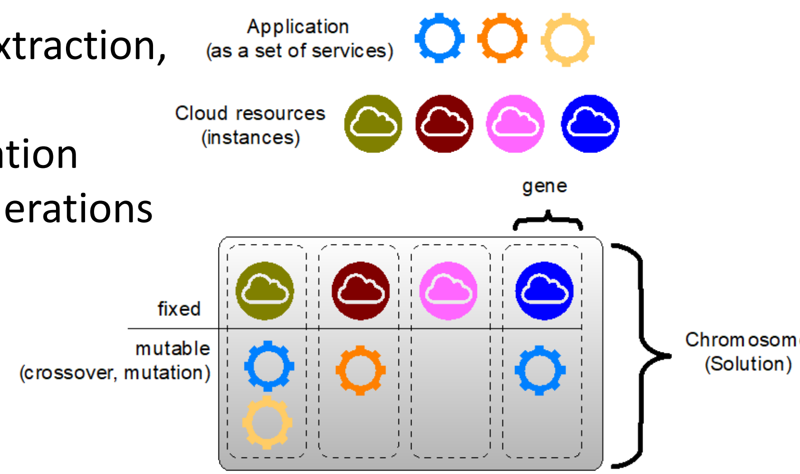


Approaches

- Distributed management algorithms exploit application modeling and structured description techniques to match and predict functional and non-functional behaviors.
- Optimization and ML/AI techniques are applied to the issues of smart allocation and management of services and resources.
- We work for a scenario where ML/AI are both Cloud services and fundamental Cloud management tools, tackling data/user-driven allocation and migration of services.

Key Results

- Decentralized algorithms for knowledge extraction, resource brokering and management
- Genetic algorithms for resource allocation optimization
- Mechanisms and system architecture for Cloud Federations
- Multi-cloud application support based on enriched application description and behavior modeling



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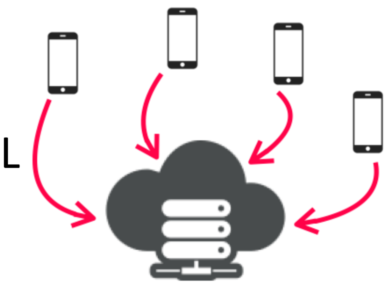
HPC Lab

Distributed machine learning for network optimisation

Key challenges:

- Data are more and more present at the **edge** of the Internet
- Current machine learning (**ML**) solutions are **centralized** (cloud-based paradigms)
- **It might not be possible to move data** from the edge
  - **Ownership/privacy** constraints
  - Lack of **network resources**

Centralised ML

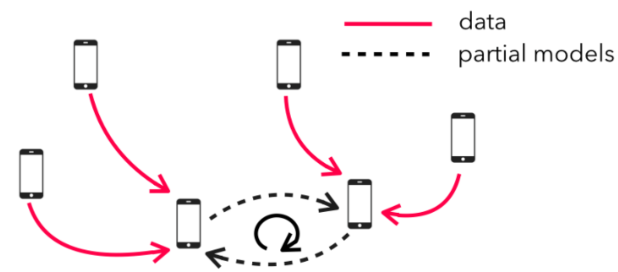


Approaches

Distributed machine learning on mobile nodes

- Apply distributed machine learning algorithms
- Identify optimal set of nodes where to elaborate data
- To optimise the accuracy vs. constraints trade-off, e.g.
  - **Privacy-ownership**: Optimal set of nodes provided constraints on where data can be placed
  - **Network resources**: Optimal set of nodes to minimize the network traffic

Distributed ML

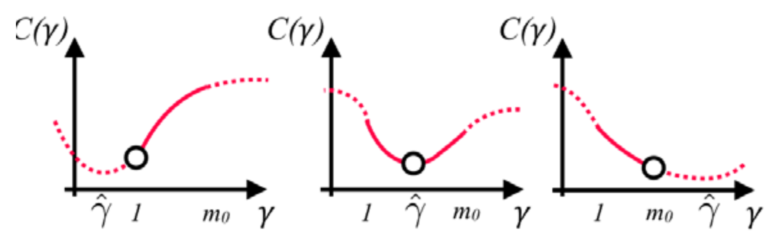


$$C(\gamma) = 2\left(\frac{m_0}{\gamma} - 1\right)\left(1+\frac{\sqrt{N}}{\gamma n_0}\right)\log_2\left(\frac{1}{\epsilon}\right) + \left(m_0 - \frac{m_0}{\gamma}\right) n_0$$

$$\hat{\gamma} = \frac{4\log_2(1/\epsilon)\sqrt{N}m_0}{2\sqrt{N}\log_2(1/\epsilon) - 2\log_2(1/\epsilon)m_0 n_0 + m_0 n_0^2}$$

Key Results

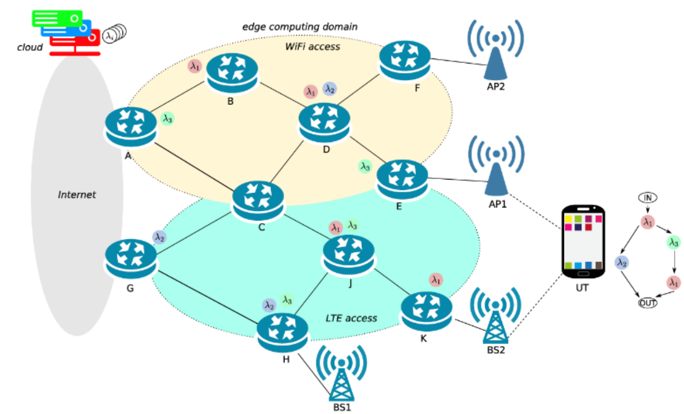
- **Models** to describe the behavior of **general distributed machine learning tasks**
- Identification of **optimal operating points** for the **configuration of the network**



Ubiquitous Internet

Key challenges:

- Cloud computing is moving towards the edge
  - **Edge computing** nodes providing services to mobile users close to where they are located
- How to optimize service provisioning in edge computing environments
  - When multiple edge servers can serve users’ requests, how to optimally allocate requests to servers?

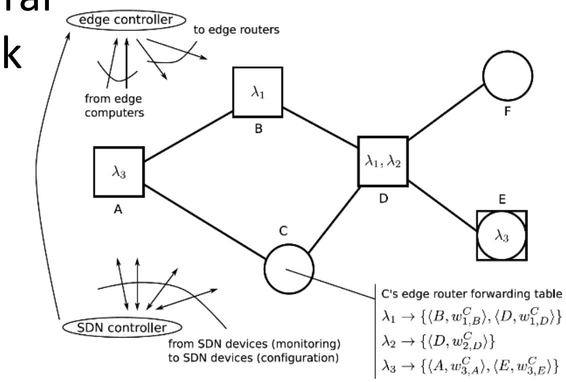


Approaches

Dynamic optimization for stateless functions

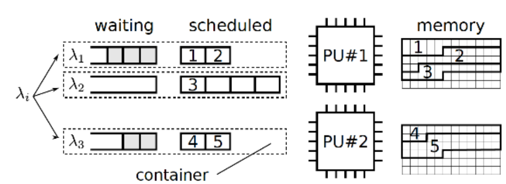
- Support **applications** such as Virtual Reality
  - Fast flow of simple requests independent from each other (stateless)
- Edge servers **collaborate** to
  - Monitor their performance and load status
  - Dynamically decide the best server to be used upon each request arrival

Architectural Framework

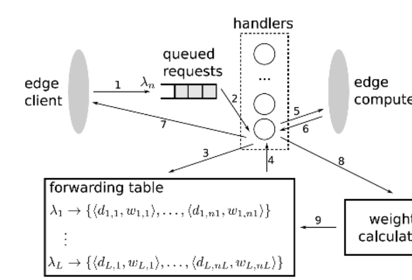


Key Results

- **General** SDN-compatible **framework** to plug any request allocation algorithm
- **Lightweight yet accurate emulation environment** to test performance of allocation algorithms
- **Performance results** for reference algorithms



Emulation environment



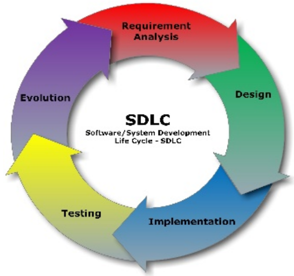
Ubiquitous Internet

SW: SOFTWARE ENGINEERING

“The systematic application of scientific and technological knowledge, methods, and experience to the design, implementation, testing, and documentation of software”

IEEE Systems and software engineering - Vocabulary

Formal Engineering of Cyber-Physical Systems



Key challenges:

- **Specification**, **Design**, **Analysis**, and **Formal Verification** of the behaviours of CPSs in order to **prevent failures** and **malfunctioning**.

Approach:

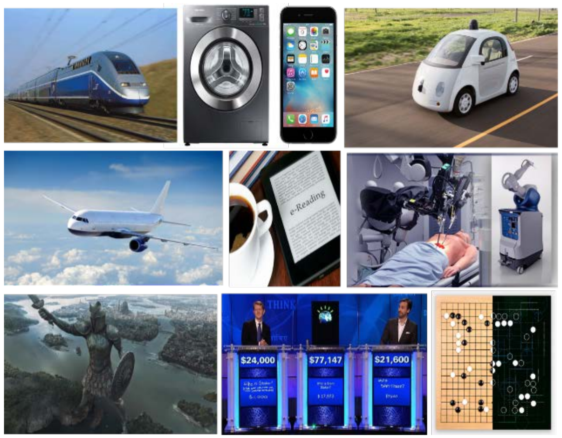
- Development of novel software system design processes supported by **requirement analysis** techniques, **automatic formal methods**, **stochastic model-based** approaches and **runtime** facilities.

Key results:

- On-the-fly/Stochastic/Statistical/Spatio-Temporal Model Checking techniques, Natural Language techniques for requirement analysis and elicitation.

Software is nowadays everywhere

Software systems will be tightly integrated in and interacting with our environment to support us in our daily tasks and in achieving our personal goals"



End user development of internet of things applications

Key challenges:

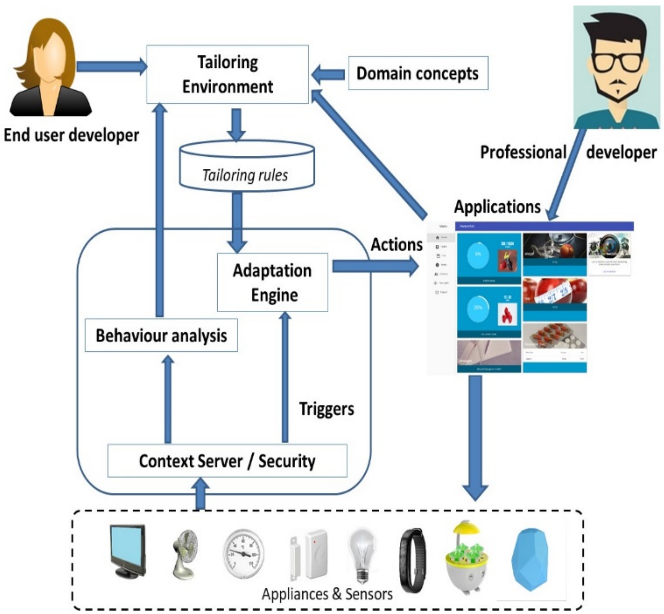
- Empowering people who are not professional software developers to configure access to future smart environments, consisting of hundreds or thousands of interconnected devices, objects, and appliances

Approach:

- Intuitive authoring environments supporting *trigger-action* personalization rules for IoT applications with various possible compositions of triggers and actions, and clear distinction between events and conditions, integrated with middleware able to properly collect, model and interpret contextual data in order to dynamically identify what rules should be executed

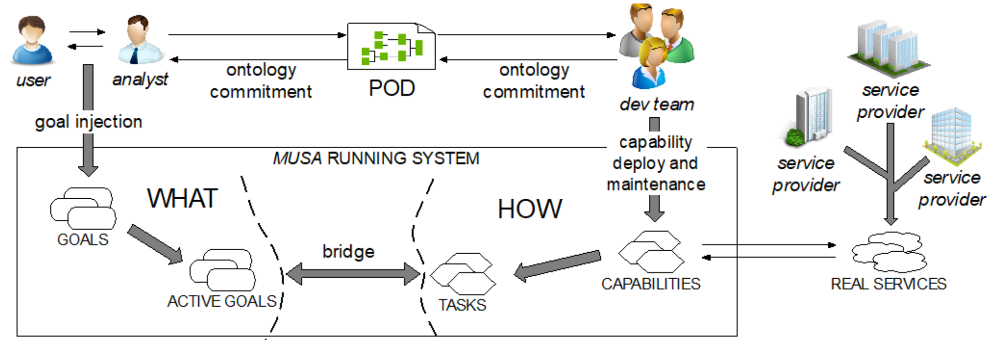
Key results:

- Platform supporting meta-design for personalization of IoT context-dependent applications, with trials in elderly homes in different countries



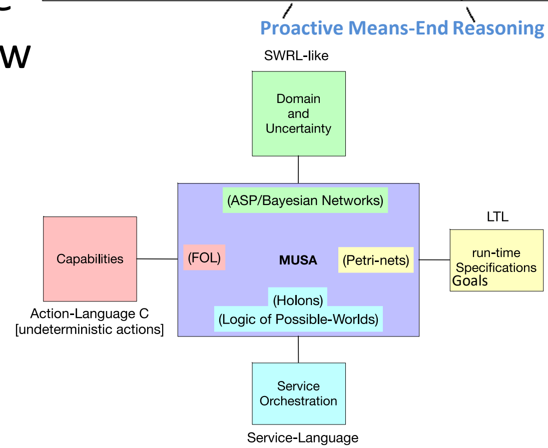
Key challenges:

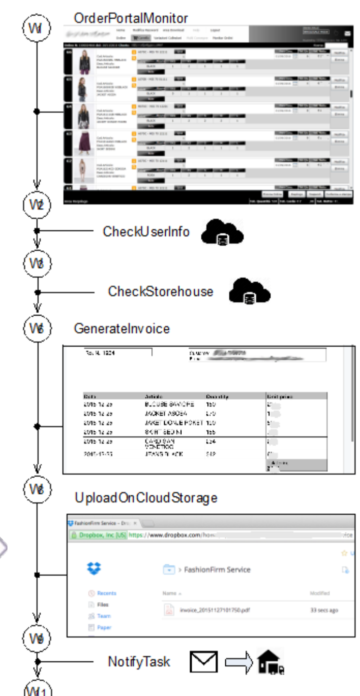
- Specification, Design, Implementation of systems exhibiting **strong adaptation**
- Research Objective: to find a **runtime solution** to changing user's needs even when the environment evolves.



Approach:

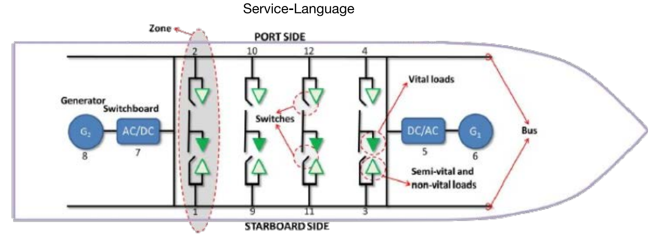
- Definition of novel adaptation techniques and algorithms introducing a proactive means-end ability in systems that are able to autonomously take decisions about how to operationalise a given set of goals.





Key results:

- Development of a **middleware** for the execution of runtime coordination of services that supports
  - runtime adaptation, **goals and capability injection**
- applications to:
  - service mashup, process execution, reconfiguration of shipboard power systems



ECOS (Engineering COmplex and Smart systems) Lab

Design and implementation of algorithms and models for big data

Key challenges:

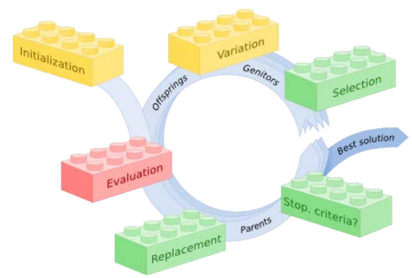
- The definition of novel heuristic approaches coming from the bio-inspired field that could help in gathering information from big data sources with the support of modern computing infrastructures

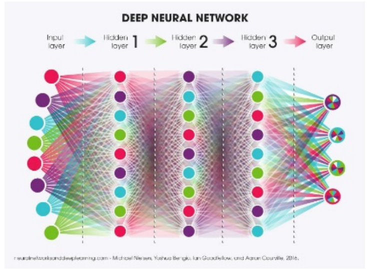
Approach:

- combination of:
  - ✓ *preprocessing* of the training set to obtain a reduced training set with the same characteristics of the original one
  - ✓ *Deep Neural Networks* to classify over this reduced set
  - ✓ *distributed Evolutionary Algorithms (*island-based models) to obtain DNN hyper-parameter values yielding higher accuracy in classification
  - ✓ further reduction in learning time by using other neural network models, as the *Wisard*

Key results:

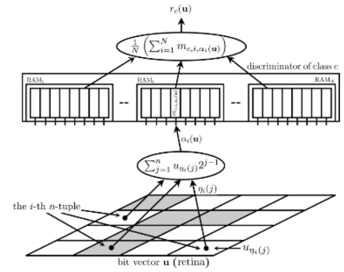
- lower execution time
- higher classification accuracy
- general-purpose research that can be applied to many different fields e.g., in the medical domain





allowed range	hidden layers	units per layer	activation function	learning steps
minimum	1	1	{relu, tanh,	500
maximum	10	30	sigmoid}	10000

original training set → training set **reduction** → reduced training set → **distributed evolutionary algorithm** searching for good **DNNs** → "best" **DNN** classifier



CI Lab (Computational Intelligence Lab)

Design and implementation of algorithms of Data Analytics for Big Data

Key challenges:

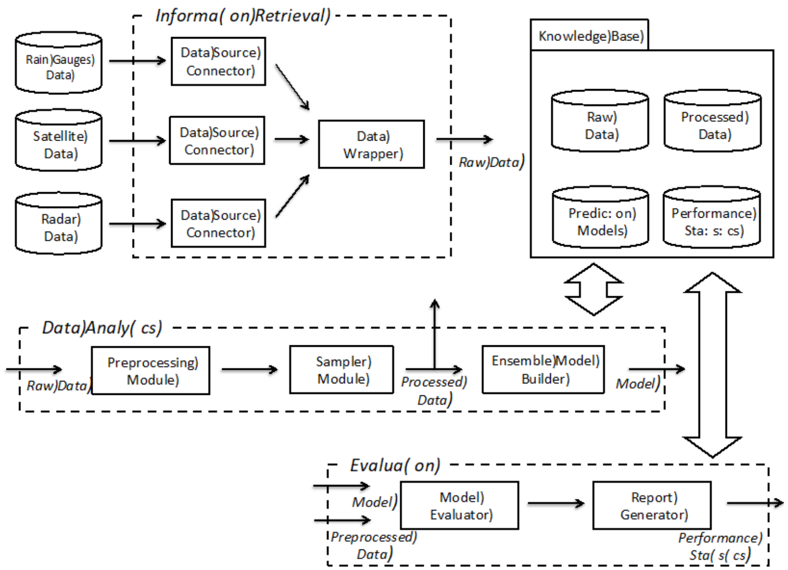
- Specification, design and implementation of algorithms for Data Analytics on Big Data, exploiting the advantages of distributed architectures, i.e., Cloud Computing.

Approach:

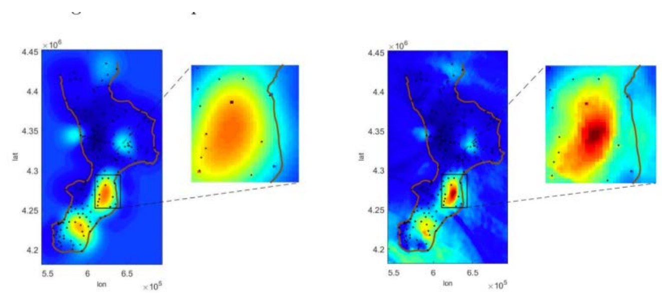
- Distributed algorithms for classification and clustering based on bio-inspired techniques, ensemble-based methods for the analysis in real-time of data streams, sampling and sampling-based querying based on map-reduce.

Key results:

- Ensemble-based and bio-inspired algorithms were applied to different real-world applications (i.e., cyber-security, disaster prevention, IoT) for their aptitude to specialize on different aspects/issues of the problem and for their capability to work with a few knowledge of the domain.



The architecture of the ensemble-based framework for rainfall estimation



Areal rainfall field estimation for Calabria

ADALAB (Advanced Analytics on Complex Data) Lab

Key challenges:

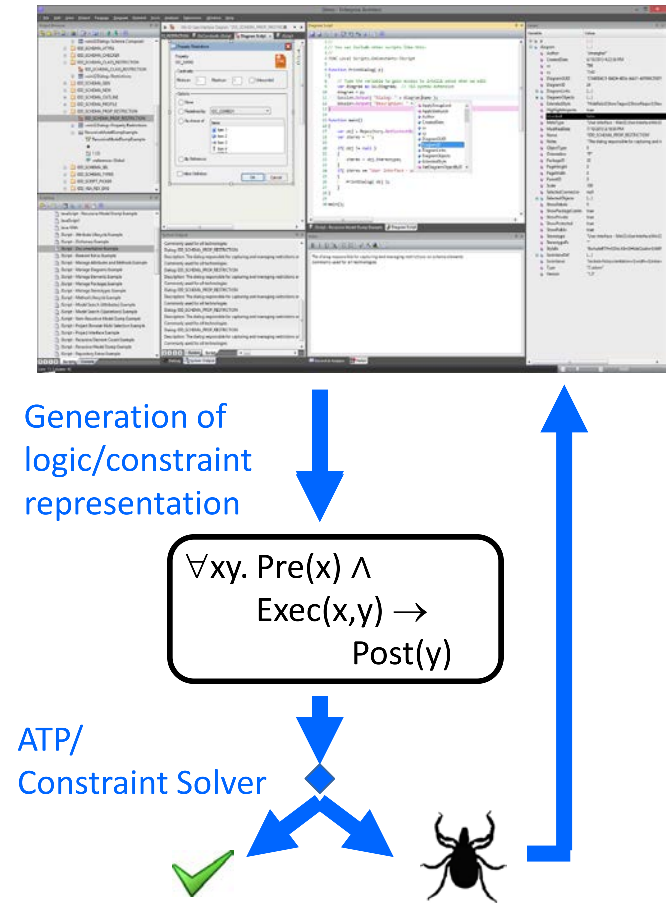
- The need of **studying and proposing software testing approaches** that supports the focused test case generation and execution **of complex software systems.**

Approach:

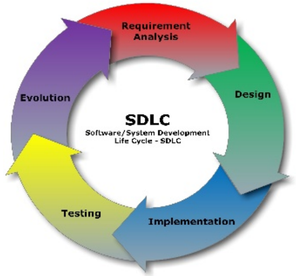
- Investigation of **innovative functional and non-functional testing methodologies** supported by automatic facilities.

Key results:

- **Innovative functional and non-functional testing methodologies**, as well as comprehensive testing approaches for **software system-of-systems** focused on the selection, prioritization and orchestration.



Monitoring and Analysis of Software Architectures and Smart Environment



Key challenges:

- **Monitoring and Analysis** software architectures easily adaptable to the IoT environments.

Approach:

- **proposals of new low cost, effective and heterogeneous solutions** in the field of monitoring and analysis of software architecture and smart environments **easily adaptable** to the IoT environments.

Key results:

- Techniques for model based specification of business process for verification and validation of functional and non functional properties.

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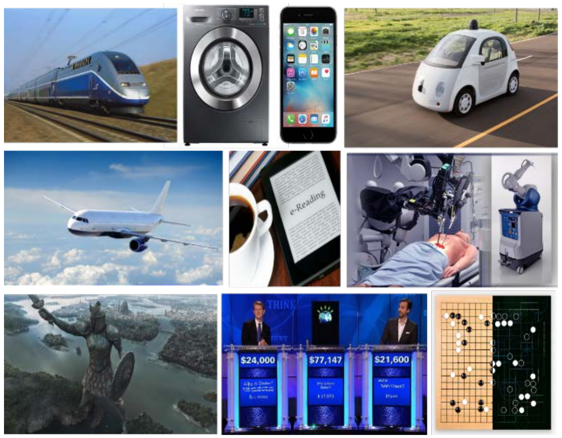
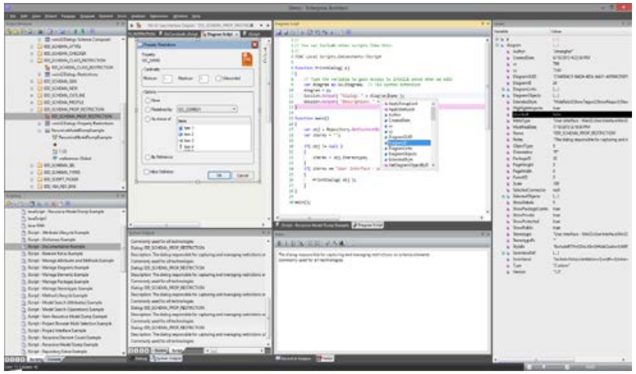
Software systems will be tightly integrated in and interacting with our environment to support us in our daily tasks and in achieving our personal goals"





Key challenges:

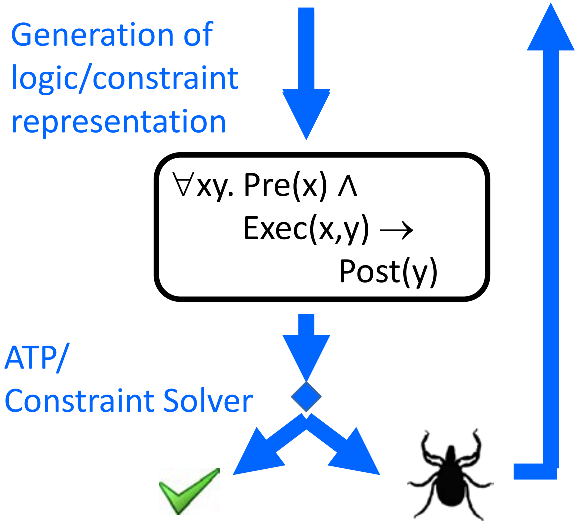
- Develop complex **software** systems whose **correct** behavior is automatically **certified**.

Approach:

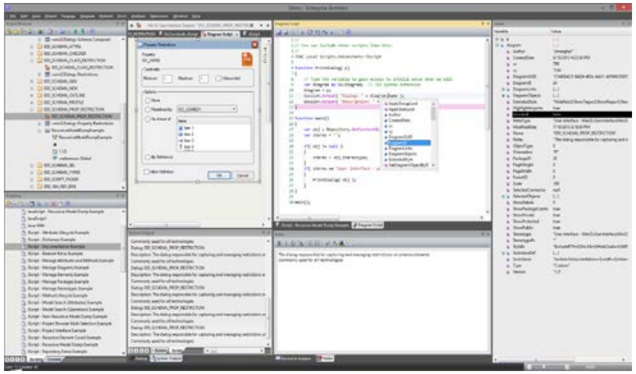
- **Logic & constraint-based** formalization and **verification** methods which are agnostic with respect to the programming language and the correctness properties to be verified.

Key results:

- **Automated Theorem Proving** and **Satisfiability Checking** techniques and tools for the formal verification of software.



Modelling and Verification of Business Processes



Key challenges:

- Modeling and automated reasoning on **rich process knowledge** (procedural behaviour, time constraints, data manipulation, semantics).

Approach:

- **Logic & constraint-based** integrated representation of knowledge about business processes.

Key results:

- **Modeling and Verification techniques and tools** based on Automated Theorem Provers, Satisfiability checkers, Constraint solvers, and Description Logic reasoners.