FRACTAL

A European Research Project

Creating a cognitive computing node and fractal edge for scalable and secure IoT solutions.

ECSEL Joint Undertaking
Electronic Components and Systems for European Leadership

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Towards Cognitive Computing at the Edge for Scalable and Secure IoT

FRACTAL's goal is to create a computing edge node that will be cognitive and fractal. It will suit a range of computing systems, from smart low-energy to high-performance ones. Such flexibility will make it a building block of decentralized and intelligent IoT.

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Project Number
877056

Project Acronym
FRACTAL

Project title
Cognitive Fractal and Secure EDGE based on an unique Open-Safe-Reliable-Low Power Hardware Platform Node

Call (part)
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Topic
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EDGE COMPUTING

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Partners
28

Countries by name and partners per country
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Person Months total
1 949.50

Number of Work Packages
9

Number of Tasks
34

Number of Deliverables
48

Number of Use Cases
8

Number of EU programs funded in this call special topic
2

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Present IoT Barriers

What limits IoT from becoming a cognitive scalable system?

Centralized Cloud

Web-applications have to deliver the quality service for end users all over the world. To do that, the computation process over the data has to be close to its source and not on a distant cloud server.

Immense Energy Consumption

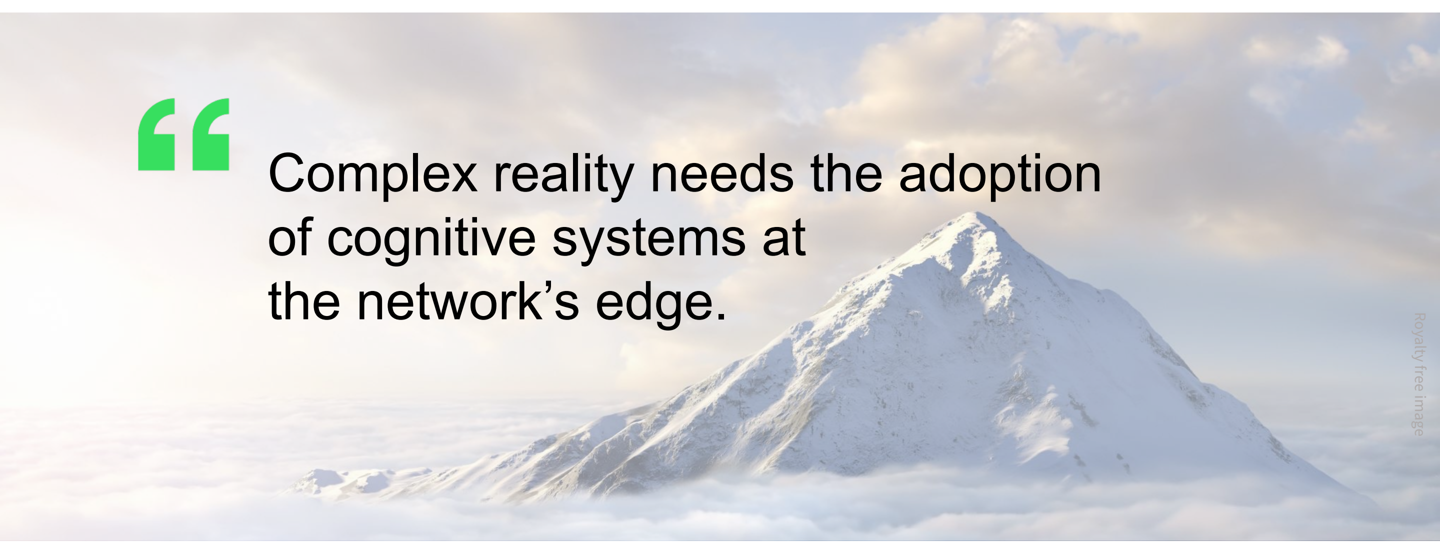
World's data centres are going to treble today's energy consumption in the following decade. The adoption of energy efficient strategies needs to come in place.

Lack of cognitive computing

The intelligence of current IoT systems relies on the cloud, which performs filtering and analysis over all incoming data. In 2020, almost 43 trillion gigabytes of data was generated.

Lack of scalable & flexible solutions

Current systems lack in bandwidth and energy resources. This affects the data transfer of some of the present and future applications, such as population health monitoring.



> Complex reality needs the adoption of cognitive systems at the network's edge.

This is the challenge the FRACTAL project is going to tackle. Read to learn how →

FACTSHEET

FRACTAL

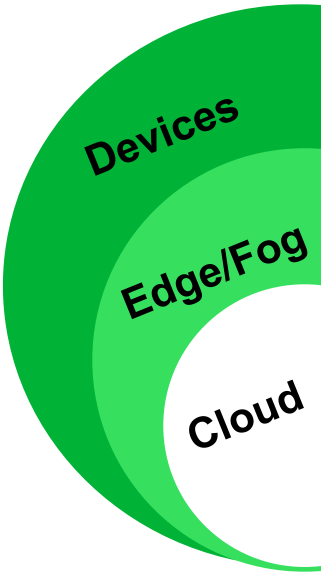
Creating a building block of scalable IoT

The boom of digitalization continues to connect more and more devices and users. Video streaming, on-demand gaming, Internet-of-Things (IoT) are blending into our everyday lives, increasing the load on the communication and computational infrastructure.

In such user-driven cloud applications, everything relies on the cloud. It alone has to process and store all the data coming from millions of devices and users every second.

Any problem with network or server can result in poor quality for the end-user and additional costs for the service provider.

Edge Computing can move this computational load towards the edge of the network. The computation will happen on the hardware nodes through which network traffic goes. This includes routers, switches, gateways and base stations or the so-called **"edge nodes."**



> *The FRACTAL project will build an Artificial Intelligence-powered computing edge node – the* ***"FRACTAL node."*** *Cognitive, secure, adaptive and scalable, it will provide* ***a new approach to reliable Edge Computing****. It will be the building block of scalable decentralized Internet-of-Things.*

FACTSHEET

Key Take-Aways

FRACTAL node for new opportunities

Edge computing layer helps to leverage low-latency, creating significant commercial opportunities. This can uncover new, exclusive sources of revenue. FRACTAL's approach to edge computing covers a wide range of applications, from low-power to high performance. Eight industrial use cases will validate and test the technology within the project duration.

Smart Systems employed at the Edge

For industrial edge computing, devices should satisfy a new set of requirements. They need to be time-predictable, dependable, energy-efficient, and secure. FRACTAL's smart system will be build from Cognitive Edge Nodes, which the cloud only need to manage and control.

AI for scalability & real-time response

AI can broaden the scope of IoT and enhance the existing services, making them more efficient. FRACTAL's Edge Nodes will be AI-powered and cognitive. They will be able to adapt to surrounding dynamic environments and learn in real-time, continuously improving their performance.

Enabling the next level of IoT

At present, in IoT and other cloud applications, everything centralizes on one cloud server. FRACTAL node will help to unload the cloud, reducing the energy costs, yet performing complex computation over data at the system's edge. This will enable real-time analytics and response.

Computing On The Edge

The amount of data generated by digital devices is escalating day by day. As the proliferation of IoT devices advances, the cloud speed capabilities and energy demands are not optimal for the complex dynamic environments. This is where edge computing steps in.

Edge Computing System

Edge computing represents a cloud computing system. It is different from the regular system in a way that it processes some of the data at the edge of its network. It distributes the computational load to routers, switches, base stations and other gateways. These edge nodes are closer to the data source than the cloud. They also have processing power and can collect or filter the data, freeing the cloud from this job. Edge computing uses this power and opens new development horizons.

Process & Benefits

Edges send only aggregated data to the cloud, reducing its workload. This improves the communication bandwidth and data transfer time. Cloud services execute only complex analytics on the pre-processed data. The information exchange between the cloud and edge nodes happens in a feedback loop. As a result, the system can make and fine-tune its actions and decisions in the dynamic environment and in real-time.

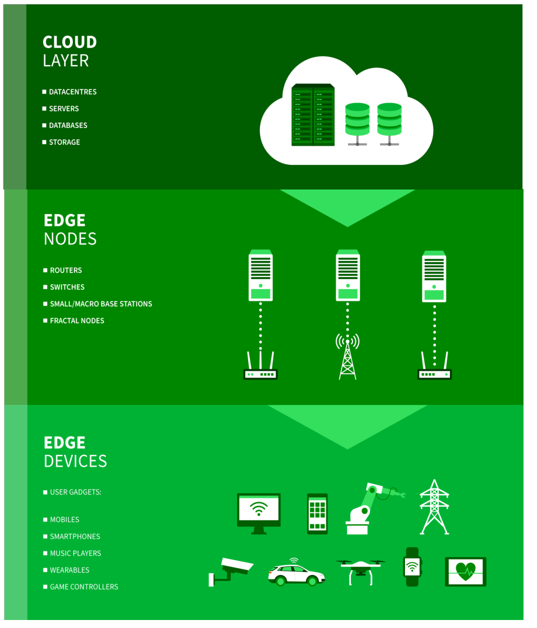
Edge computing brings high-bandwidth, low-latency access to latency-dependent applications. With edge computing, operators can open their networks to a new ecosystem and value chain. As a result, new cloud-native applications will flourish.

Fog vs Edge

Edge computing takes place on the devices connected with sensors or on a gateway device that is close to them. Fog computing moves the edge computing activities to processors connected to the LAN or into the LAN hardware. These devices can be more distant from the sensors and actuators. In summary, fog computing processes the data within a fog node or IoT gateway within the LAN, while edge computing processes the data on the device or sensor itself without transferring it anywhere. Both of them push the intelligence closer to the source of the data.

AI for Cognitive Edge

Recent systems-on-a-chip (SoCs) innovations made computer chips strong enough to run complex



Visual description of edge, fog and cloud computing; difference & connection between the three layers.

algorithms and operating systems. AI and ML methods can make edge nodes cognitive and adaptive, increasing the efficiency of the whole system.

With an intelligent edge performing advanced data analytics, industries will be able to extract valuable insights at the right time and place. For IoT it means that complex computations will happen on-site.

> *As a result,* ***future IoT*** *will become more* ***responsive*** *and* ***empathic*** *from the* ***end-user's perspective.***

FRACTAL: Empowering Edge Computing

Secure and scalable edge computing is still a concept under development. The aim of the FRACTAL project is to turn it into reality. This will be done by creating a cognitive computing node.

Ambition

The FRACTAL project aims to create a reliable computing edge node. It will suit a range of computing systems, from smart low-energy to high-performance ones. Such flexibility is what will make it a building block of scalable decentralized and intelligent Internet-of-Things. FRACTAL's ambition extends across hardware and software. It covers aspects related to AI, safety, security, low power, and edge integration.

Strategic Objectives

1: To design and implement an open-safe-reliable hardware platform. It will be used for building the cognitive edge nodes of variable complexity.

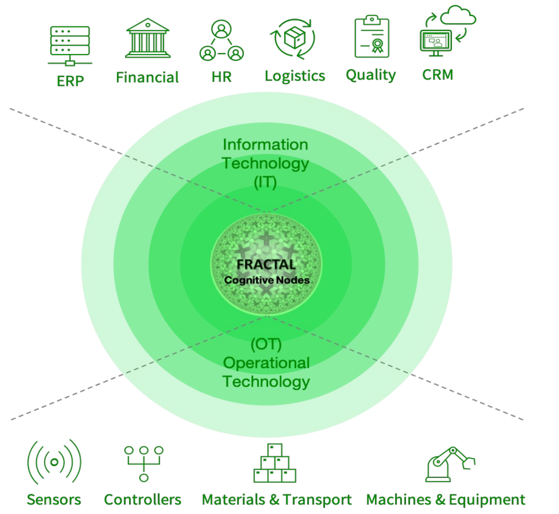
2: To guarantee extra-functional properties of FRACTAL nodes (dependability, security, timeliness and energy-efficiency).

3: To evaluate and validate data analytics with AI. To identify the largest set of working conditions, while preserving safe and secure operations.

4: To integrate fractal communication and remote management features into the nodes.

Smart System at the Edge

FRACTAL project puts in place a new Smart System paradigm. The cognitive node it creates, will bring the intelligence to the edge of the network. As a result, the FRACTAL node will pave the way to a new generation of smart systems. In such systems, the cloud will only need to manage and control the edge nodes.

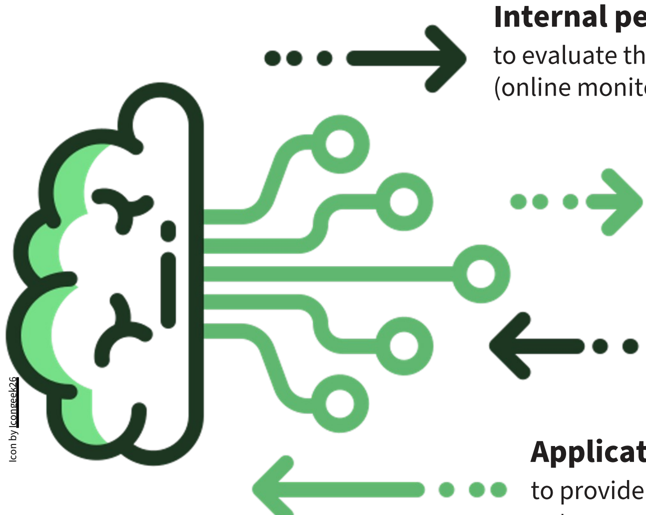


Visual representation of the FRACTAL's cognitive node location in the context of Information and Operational Technology.

Node Cognitivity

Artificial Intelligence, supported by internal and external architectures, will make the node cognitive: it will be able to forecast both its internal performance and the state of the surrounding world. It will learn and improve in real-time, delivering new services for the environment's demands. This will enable the intelligence of the whole system.

Features of the FRACTAL node that will ensure its cognitivity:



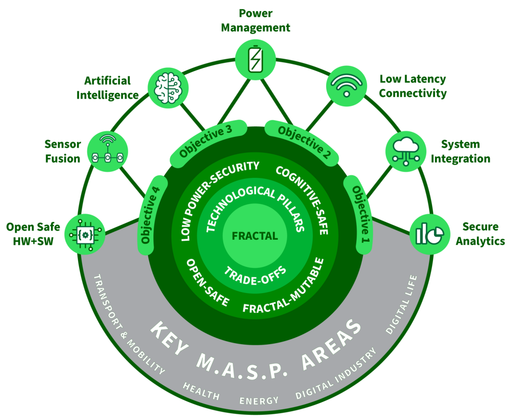
Internal performance metrics supervision
to evaluate the fulfilment of the desired goals (online monitoring).

Operating environment modelling
to provide context-awareness for the Cognitive System(advanced sensing & computer vision).

Integration of computational capacity
to process data, models, and AI algorithms (low-power multicores and hardware acceleration).

Application of AI methods
to provide Smart Systems with learning, prediction and autonomy (artificial intelligence).

Technology Pillars of FRACTAL

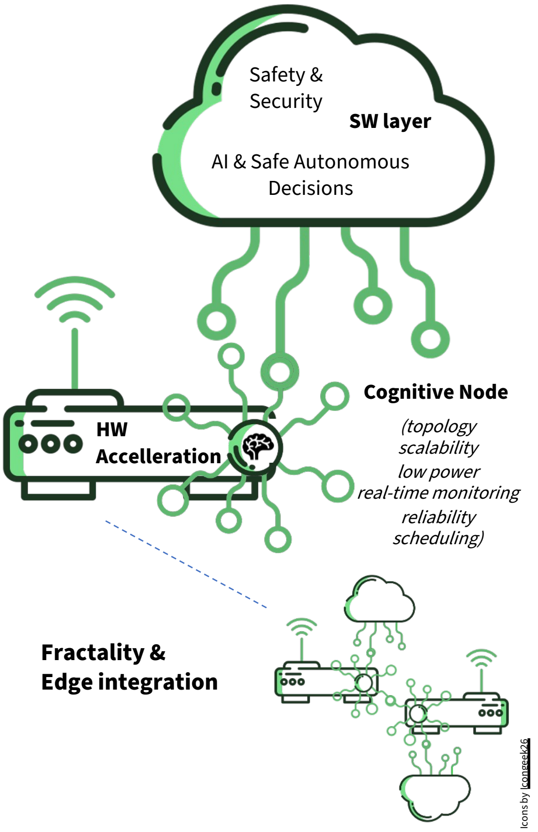


Project technology pillars and objectives; held under the Multi-Annual Strategic Plan (“M.A.S.P.”).

The objectives of this project are held under four technology pillars. They represent crucial trade-offs between all specifications and characteristics of the node's hardware and software that need to be in place.

The node should have open-safe-reliable and low power architecture. While being low power, safe and secure, it should have high performance capabilities. It should also be cognitive and autonomous, to reduce cloud services. Lastly, the node will use novel communication (i.e., 5G) and storage techniques. The fractality of their configuration will allow the network's scalability.

Edge computing will create a paradigm shift from the device and original equipment makers. This will concern everything from how such products are sold to how they are installed and serviced. These changes will affect all players in the tech stack, consumers in a vast array of sectors, and many companies and leaders looking to have a role in it. This is the key opportunity, the forthcoming paradigm shift that FRACTAL aims to be part of.



FRACTAL’s schematic system and node integration.

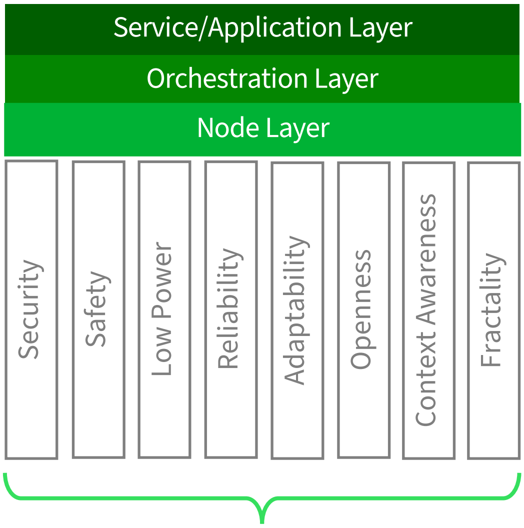
FRACTAL High Level Architecture

FRACTAL from a high-level point of view can be seen as a simple layered architecture with three layers: a **node layer** that refers to the element that provides certain low-level characteristics such as AI Accelerators or computing power. Over the node layer, a **service orchestration layer** is built that enables to manage the services that run over the node. Finally, the **application layer** describes the business logic for the different applications / use cases.

Fostering the notion of *fractality*, the node layer includes both the Cloud Node and the Fractal Edge Node, and the Fractal Edge Node references both the HW Edge Platform and the Low-Level SW Platform (which includes OS, drivers for HW, etc.). Components on the application layer will be able to access characteristics provided by the Node Layer (such as AI accelerators).

FRACTAL High Level Features

A FRACTAL feature is a distinguishing characteristic of FRACTAL, visible to users that will configure FRACTAL for



FRACTAL features provide dimensions & characteristics

their use cases. This is, features are high level concepts that may crosscut the distinct layers of the architecture and that a certain use case may (or may not) require. The diagram above presents the FRACTAL high-level features.

The concept of “feature” allows a consistent abstraction to be employed when making choices from a whole FRACTAL product configuration all the way down to the deployment of components within a low-level subsystem. It also enables to address the variability introduced by the use cases to build a product family.

FRACTAL System Features & AI

FRACTAL features	Related AI concepts
Decentralization	Multiagent paradigm, orchestration paradigms, distributed learning
Context-awareness & Adaptability	Orchestration paradigms, decision-making

Association of AI concepts to Fractal features

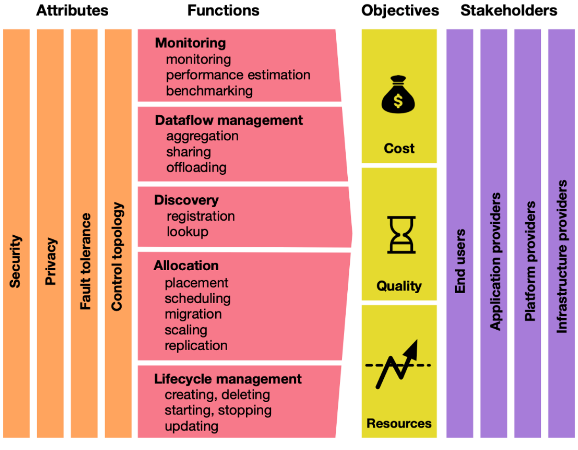
- **Multiagent paradigm & Agent autonomy**

Distributed artificial intelligence is required when individual components of a learning system do not have enough resources to achieve their objectives. This is a common situation in the edge-cloud continuum. Here, multi-agent systems (MAS) can be used to provide cooperative and collaborative capabilities. Agents are a computational abstraction which can set objectives and act to achieve them. Agents may possess various degrees of intelligence, defined by their reactivity, sociality, proactivity, and learning capability. On distributed application level, agents have distinct roles and behaviors, and they need to negotiate and share their resources.

In open systems, such as the Internet of Things (IoT), a MAS often needs to dynamically reorganize itself to adapt and to evolve in response to changes in the participating agents or in the environment. These aspects ultimately facilitate individual and collaborative learning to improve operations towards common goals and proactive behavior(s).

- **Orchestration paradigms**

The cyber-physical resources of a computing continuum may comprise sensors, actuators, and other connected user devices. Managing these resources is often referred to as orchestration. It aims to reach certain objectives set by stakeholders such as end users and infrastructure providers.



Continuum orchestration taxonomy.

Industrial Applications

From Research to Practice

As FRACTAL is a research project, there is a need to ensure the quality and relevance of its results. This is also important for further adoption of the technology. Thus, integration, verification and validation activities are an essential part of the project.

The FRACTAL project embraces **8 industrial use cases**. They serve as a testing ground for the project's technology. Half of the use cases will verify the integration of the FRACTAL system and the other half will prove and benchmark it. Both vertical (specific industries) and horizontal (wide applications) use cases are part of the project.

Edge computing layer helps to leverage low-latency that creates significant commercial opportunities. This is critical for uncovering new, exclusive sources of revenue. Besides, it enables network awareness and optimal allocation of resources, which can benefit both customers and operators.

FRACTAL node has four main application fields:

Transport: Autonomous vehicles

Digital Life: Engineering

Digital Industry: Industry 4.0

Energy: Energy Consumption and Environment

Use Case 1:

Edge Computing for Engineering and Maintenance Works

Two safety-conditions monitoring solutions for civil engineering.

The construction sector is currently one of the less automated sectors. The applications of recent technology innovations can benefit it in many ways. The construction processes infrastructure and health and safety conditions can be improved. The speed and efficiency of construction activities can be maximized. Risks of structural and safety failures can be scaled down, reducing the long-term costs. Digitalisation of the equipment will prolong the life-time of different structures with predictive maintenance.

First Solution

The solution focuses on monitoring and detecting building hazards. Drones (Unmanned Aerial Vehicles (UAVs)) will conduct the piloted visual inspections in near-real-time. This solution will deploy a computing edge infrastructure based in micro-services.

Conventional inspections of structures are nowadays based on visual investigation methods. It is hard to access the large structures for a detailed inspection. For instance, bridges, chimneys, towers, dams, industrial power plants, historical buildings and monuments. These structures usually need a complex technical inspection, especially, of the critical hard-to-reach components. At present it is possible only with special equipment (e.g., under-bridge units, elevating platforms) and personnel.

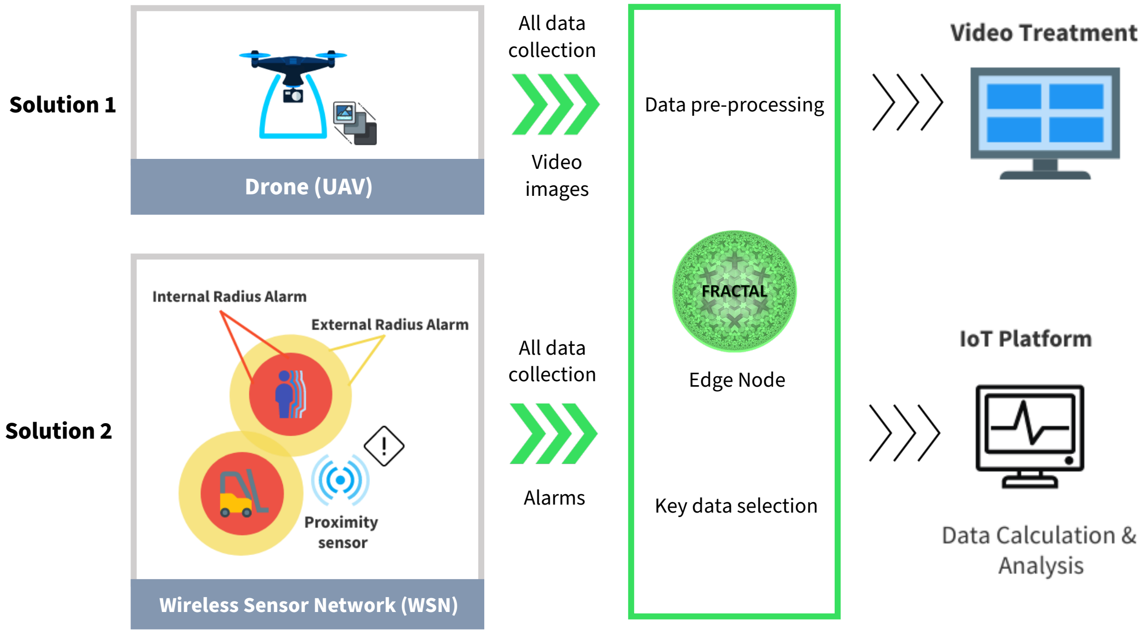
The rapid development of UAVs suggests they can soon be able to do this job. They will collect images from the construction sites and structures. The AI model will then analyse them and extract detailed information.

Second solution

In this solutions, sensors will be worn by workers and placed in the machinery and on the construction sites. The sensors will detect dangerous situations during the construction processes. They will inform the status and position of both worker and machinery over the Wireless Sensor Network (WSN) in real-time.

The raw data from the construction site will go to the FRACTAL node through WSN. Then the key insights will be sent to the IoT platform. The platform will register possible dangers, establish proximity alarms and emergency protocol.

This solution will help to avoid workers run-over by machinery and other potential risks.



Use case end-to-end solutions visualisation.

Objectives & Benefits

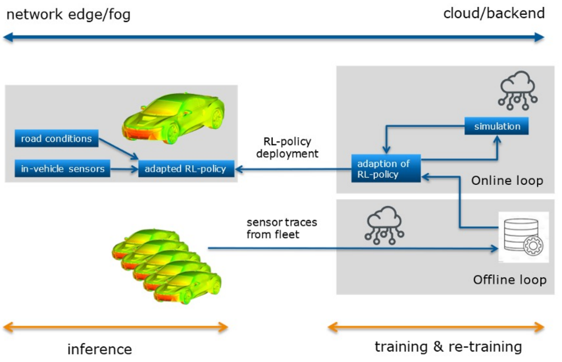
✓ Complex physics knowledge integration	→	Increased adaptivity and resilience of the system
✓ Application of AI methods	→	Learning & forecasting capabilities of systems, following previous complex paradigms & rules

Use Case 2:

AI-based control strategies for thermal management

Reinforcement Learning based Thermal Management for BEV

Existing automotive control strategies are fully reliant on model-based strategies. These techniques imply a high calibration effort and the ability to perform self-learning through observations is very limited. The focus of this use case is on the thermal management application for cabin heating mode selection. It will, therefore, contribute to integrate the environmental influences and changes as a fundamental part of the system, among other benefits, like potentially increased product quality and increased efficiency for the development of customized controllers.



Reinforcement Learning based Thermal Management

Three model operations are defined:

1. Model inference of the initial state AI-based model, to replace the conventional control
2. Model adaption, to cover the model blind spots from limitations of the model training input data and to adjust to vehicle specific parameters
3. Cloud connection to create training infrastructure of the system.

Objectives & Benefits

✓ Implement Machine Learning based models	→	Improve energy efficiency and reduction of environmental pollutants
✓ Develop the initial state model and self-adaptation of models	→	Increased adaptivity and resilience
✓ Consequential enactment of control strategies	→	Single vehicle learnings to improve the behaviour of many

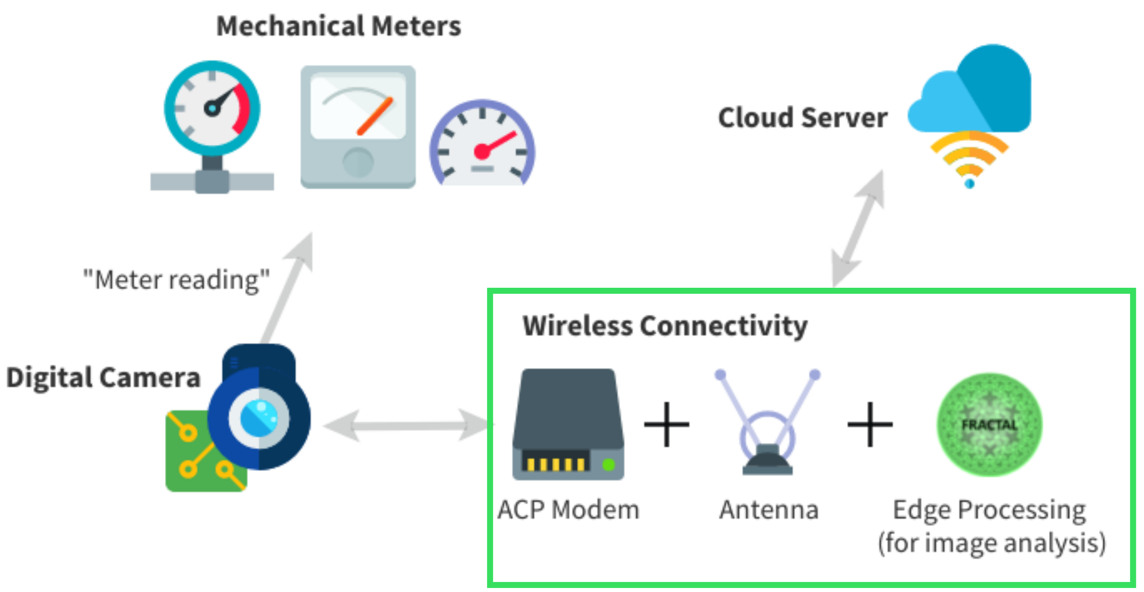
Use Case 3:

Smart Meters For Everyone

Intelligent IoT meters with remote access.

Smart metering is a hot topic and one of the top use cases for the internet of things. The goal is to read the meters from a distance by connecting them to the internet. The utility providers will be able to receive information from them over the network, without the need to visit customers' site.

One of the steps to smart metering is the electrification of the equipment, which is not yet in place. It should cover both meters and the infrastructure around them. The challenge is that meters often work with pure mechanical principles. They lack power supply and an electronic interface for accessing their stand.



Smart Meter Diagram. Schematic visualization of the use case solution.

The alternative would be a low-cost non-invasive battery-operated device with a camera. The camera would take pictures and do the pattern recognition of the meter stand. The FRACTAL node will be built on the device and pre-process the data. The system would then send the extracted values over the cellular network.

Such a device needs to be at the extreme edge, so its size should be in the range of a 3-5 cm2 to fit on a meter. It should consume as little power as possible, so it can stay in the field for many years. It also needs to be efficient and reliable in reading the meter stand, no matter the lighting conditions.

Last but not least, it has to send the data over a wireless channel, even if there is a limited connectivity at the location.

To electrify infrastructure and replace them with a smart device is a big investment. In this use case, the idea is to adapt a FRACTAL node for low power operation and cost efficiency, converting the traditional meters into IoT capable smart ones.

Objectives & Benefits

✓ Low power consumption	⟶	In the field for many years
✓ Reliable meter reading	⟶	Accurate even in suboptimal lightning conditions
✓ Small size (3-5 cm2)	⟶	Can be on extreme edge
✓ Wireless Connectivity	⟶	Stays connected even in isolated environments (e.g., basements)
✓ Security	⟶	Forbidden access prevention system; user data protection

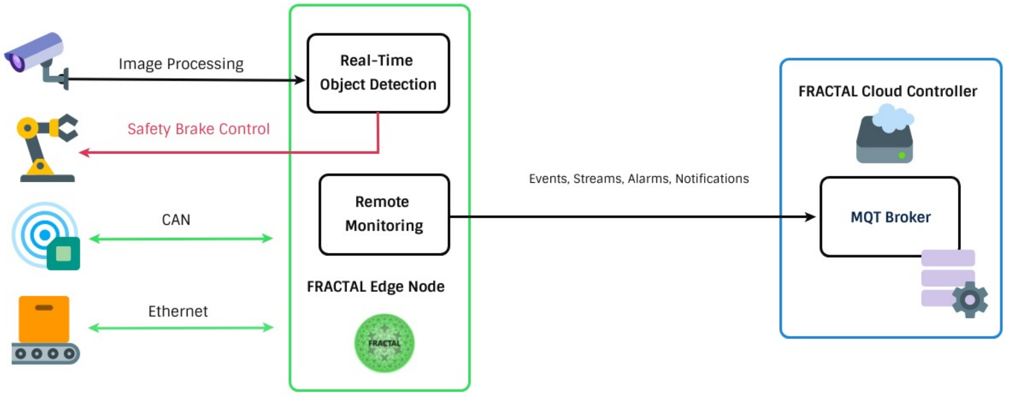
Use Case 4:

Low-latency Object Detection in Industry 4.0

An object detection algorithm as a FRACTAL building block.

This use case will focus on building a sensor fusion for edge computing. Securing the bounds of execution time is critical for such functional safety systems. The advanced hardware acceleration and AI will guarantee the execution time for object detection safe systems (real-time).

The FRACTAL platform will also enable remote monitoring and/or local control of critical industrial systems. The AI/ML integration will make the system capable of predictive maintenance, autonomous robot guidance and other industry applications. The outcome will advance digitalization and boost the industry 4.0 paradigm.



Visual schematic representation of the use case solution.

Objectives & Benefits

✓ Latency & Throughput	→	To enable safety-critical real-time applications
✓ Power dissipation	→	From data center to the edge for power efficiency
✓ Heterogeneous compute arch integration	→	With processing and memory HW accelerators to comply with system's resources
✓ Application agility	→	Reconfigurable HW to adapt to changes of AI/ML algorithms

Use Case 5:

Autonomous train operation

Automatic accurate stopping and safe passenger transfer AI-powered system.

This use case will deliver a higher level of autonomy in urban vehicles (e.g., trains). It will also help to align them with European railway normative. The system will incorporate AI and high-performance computational capabilities, achieving increased dependability and safety.

A multicore platform with HW support and AI acceleration will enable the node's safety and high performance. Such hardware substrate will meet the challenging requirements of autonomous train operations.

FRACTAL approach will enable the autonomous (driverless) train operations. Real-time and safety-critical computing platform will ensure the system's correct performance. AI-enhanced technology will follow strict standards and safety regulations.

Computer Vision (CV) and Artificial Intelligence (AI) techniques will improve different autonomous train operation functionalities:

- stopping precision
- Visual odometry
- rolling stock coupling operation
- person and obstacle detection

CAF Istanbul's fully automated metro.

Objectives & Benefits

✓ Automatic train station platform detection	→	To enable CV&AI based automatic train approximation to accurate train stop
✓ Automatic accurate stop at door equipped platforms aligning the vehicle and doors	→	Precise localization to reach accurate stopping point and managing automatic train operation
✓ Safe passenger transfer	→	Avoid door opening if the train and platform doors are not precisely aligned

Use Case 6:

Intelligent totem

AI-based smart mobile totem for shopping malls and smart cities.

The use case represents an AI-based smart mobile totem for retail stores and shopping malls. It will provide personalized advertisements and product recommendations. It will also have a destination/product wayfinding services. For an immersive user experience, the platform will evolve into anthropomorphic robots.

The adoption of the system goes far beyond the retail sector. Smart cities could use them to provide mobility, safety, security, logistics and goods delivery services. The heterogeneous sensors like cameras, microphones and proximity will make the system context-aware. Edge computing will help to elaborate on huge amounts of data the collect. The processing algorithms employed at the edge will extract meaningful information in real-time. This will make the system autonomous and able to execute such tasks as patrolling and security monitoring. It would be especially helpful during the night and other closing hours of the facility.

An approximate visualisation of the use case.

Objectives & Benefits

✓ Customer support and personalized advertising	→	Immersive customer experience and added value
✓ Surrounding perception processing	→	Video and audio processing to infer information about the customers
✓ Adaptive intelligent and mobile system	→	Displayed content and actions adaptation to the customer and environment

Use Case 7:

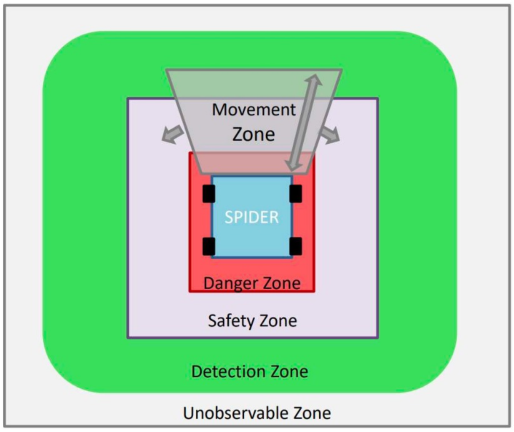
Smart Physical Demonstration and Evaluation Robot (SPIDER)

An autonomous robot prototype.

This use case explores the integration of the FRACTAL Cognitive Edge Node into the autonomous robot SPIDER. It will test FRACTAL's ability to perform computational intensive vehicle functions at the edge of the network. The successful implementation will enable the robot to send only aggregated data to the cloud. It will lower down the communication bandwidth requirements, fostering node autonomy, while the cloud will only manage and control.

A picture of the SPIDER robot.

The Cognitive Edge Node platform will bring about two SPIDER functions. It will be able to maintain safety and security by providing high availability at the same time.



Visual representation of the system's awareness.

Objectives & Benefits

✓ Co-execution of safety-and security-relevant, AI-based tasks	→	Without compromising any of the requirements of these functions, due to reconfigurable FRACTAL system
✓ Fail-operational capabilities implementation	→	Even in the presence of common-cause faults

Use Case 8:

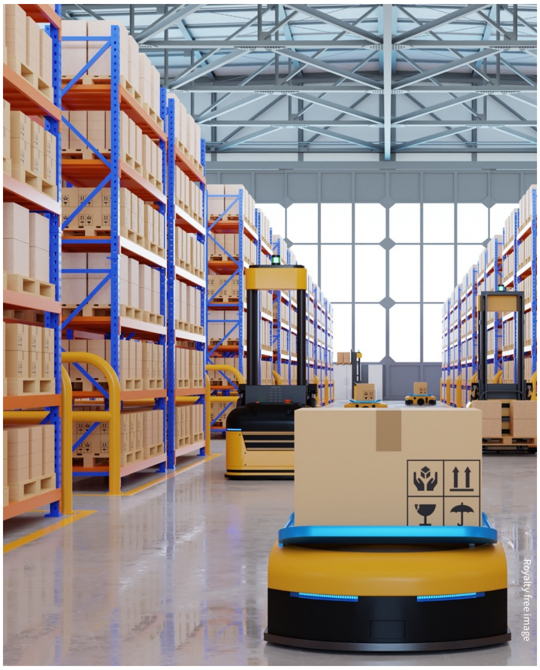
Warehouse with Intelligent Autonomous Shuttles

Automatic accurate stopping and safe passenger transfer based on computer vision and AI-enhanced techniques

The use case employs the FRACTAL technology for a warehouse with intelligent autonomous shuttles. Cognitive computing will enable swarm intelligence, thereby improving availability, throughput and safety.

The following benefits are expected from the SWARM capabilities:

- **Cooperation** between the shuttles to provide high and reliable warehouse throughput for the goods.
- **Adaptation** of the FRACTAL–based shuttle to upcoming jobs and failures (e.g., failure of a shuttle, failure of a lift, failure of a track).
- **Obstacle avoidance and resolution**. Shuttles will avoid obstacles by adjusting paths and collaborate to clear them if possible.
- **Improved availability** through the routing algorithms. Optimization of the performance and failures to enable fast delivery of goods, even when resources become faulty or degrade (e.g., track, lift or shuttle).



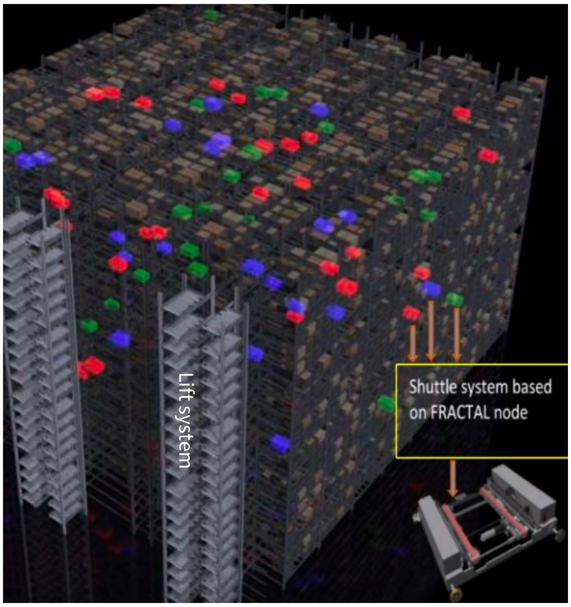
An approximate visualisation of the use case.

- **Safety.** Systems will co-operate to support safety-critical scenarios. Among them is collision avoidance between shuttles and human engineers during online-maintenance.

Delays in the warehouse operation are critical. They can cause a domino effect on the whole supply chain. Therefore, the goal of this use case is to improve the warehouse throughput.

Artificial Intelligence techniques will optimize the work of the automated shuttles. This will cover warehouse goods handling, storage and retrieval. AI will organize and analyze the incoming data, improving the throughput in real-time.

The FRACTAL node will satisfy high computational requirements needed for the AI algorithms. It will provide sufficient power and storage resources for this type of tasks.



Depiction of automated shuttle system in a warehouse.

Objectives & Benefits

✓ Predictive maintenance	→	Optimization of the tasks that led to failure or low performance
✓ Adaptive system	→	Independent situational adaptation of the system within the warehouse
✓ Power optimization and improved storage strategy	→	Location and spread optimization of high-velocity goods; minimization of congestion and retrieval efficiency
✓ Route optimization with AI	→	Delivery efficiency and higher throughput
✓ Pick-up order (productivity)	→	Optimized system directed picking pattern identification
✓ Defined bulk processing of order	→	Order's processing time calculation based on its size to deliver on time

FRACTAL Impact
KPIs

37

New innovative products on the market as a result of the project

8

industrial **use cases** within the project duration

200

Customers
in 5 years commercial impact

Up to **25%**

Turnover growth
of participating organizations

650

Employments
to exploit the results of the project after 5 years

30M€

investment to continue the research activities and TRL9 Actual system proven in operational environment.

21 scientific publications

in peer-reviewed high impact journals and joint public-private publications, to broaden further research activities

40

R&D projects
to come out after FRACTAL

5

Patent
applications

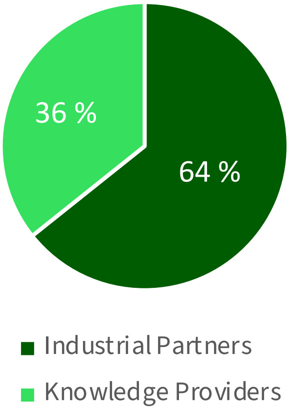
>20

Open source
releases

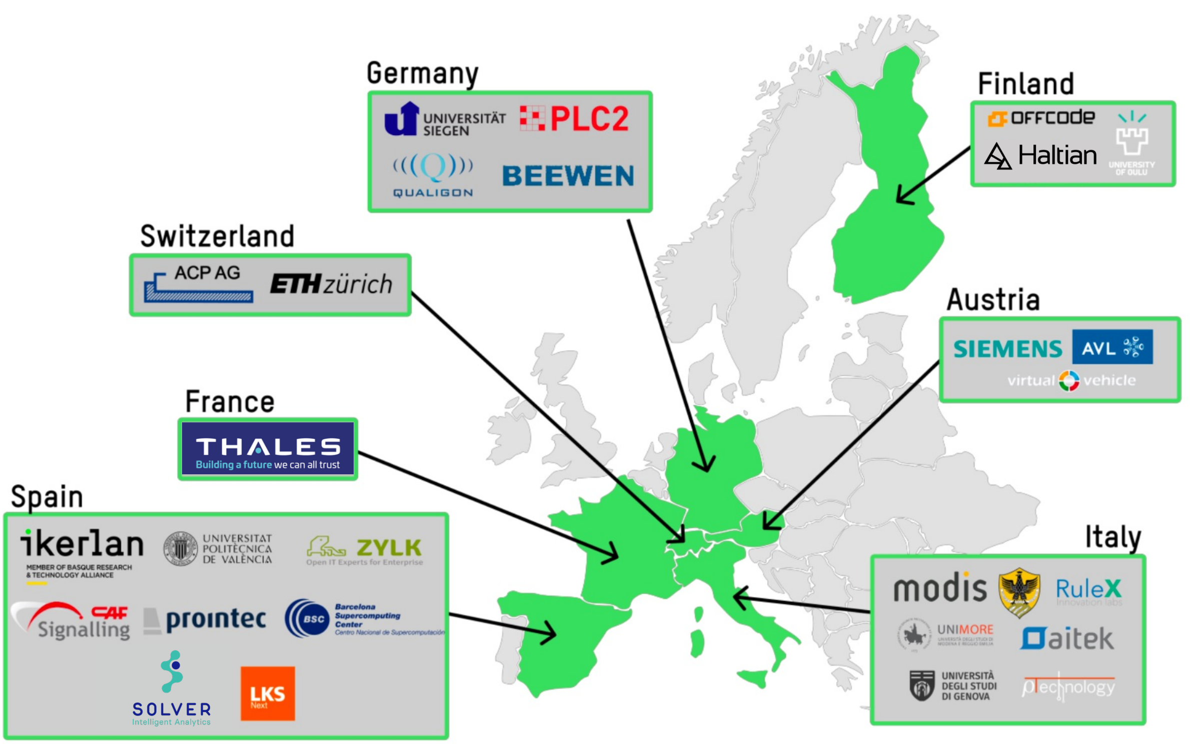
Project Consortium

FRACTAL brings together knowledge, expertise and innovation potential of major European actors. Among them are leaders in edge computing and other key application areas of the project.

Industrial partners bring technical expertise and commercial exploitation prospects of the project results. While the knowledge providers, such as universities, ensure the excellence of the project.



The consortium is led by IKERLAN - a RTO with extensive experience in management of large EU projects and acknowledged expertise in integrating



The project consortium on the world map. In total, there are 28 partners from 7 countries.

[Learn more]

FRACTAL

Coordinated by:

ikerlan

MEMBER OF BASQUE RESEARCH
& TECHNOLOGY ALLIANCE

IKERLAN has a proven track record of managing large scale research and commercial projects. IKERLAN Innovation work leading big project such as SAFEPOWER, MULTIPARTES, LABONFOIL, BATTERIES2020, among others.

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