EUCloudEdgeIoT.eu
Open Continuum

Developing a Reference Architecture for the Continuum

Concept, Taxonomy and Building Blocks

Grant Agreement No.: 101070030 **Topic:** HORIZON-CL4-2021-DATA-01-07
Call: HORIZON-CL4-2021-DATA-01 **Type of action:** HORIZON-CSA

Contents

Introduction

Cloud and edge computing are essential technologies in a computing continuum to ensure data is managed more efficiently – closer to the originating source rather than transmitting raw data to data centres. As recent studies suggest, data processing is moving closer to the edge. Thus, a stronger focus on the far edge and IoT part of the continuum spectrum can provide significant benefits, such as reduced communication costs, reduced storage needs, and lowered energy consumption. Moreover, the integration of artificial intelligence and machine learning would provide particularly high benefits for citizens and businesses in such a scenario, like increased local data sovereignty, stronger privacy protection, and tighter sense-reason-act loops based on localised, low-latency networks and processing nodes. These trends call for a shift towards the technical and business convergence of the so-far formally separated Cloud, Edge and IoT domains.

Different EU research funded projects are tackling it from different perspectives, generating reusable solutions and know-how addressing some aspects of the continuum.

This paper analyses the homogenisation needed, providing the initial version of a common taxonomy as a unified language for all actors of the cloud, edge and IoT domains, as well as the initial set of building blocks, and associated taxonomies, to set the basis for the development of a Reference Architecture for the continuum.

About the authors

This work was performed by Task Force 3: Architecture leader, part of the OpenContinuum project consortium, within the EUCloudEdgeIoT initiative.

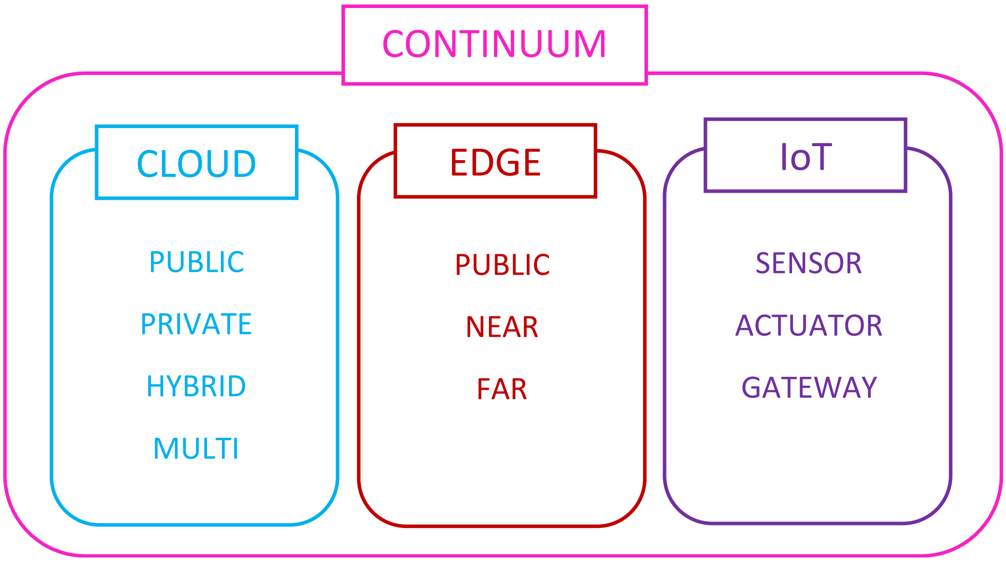
Task Force 3 aims to foster a common vision on Continuum computing, providing a homogenised language and a reference architecture to set the basis for a European standard, positioning Europe ahead of the global competition. The work presented here has been further validated with the engagement of 46 ongoing research projects in the fields of edge, cloud and IoT (mainly belonging to the following Horizon 2020 and Horizon Europe topics: ICT-40-2020, ICT-50-2020, ICT-56-2020, HORIZON-CL4-2021-DATA-01-05, HORIZON-CL4-2022-DATA-01-02, HORIZON-CL4-2022-DATA-01-03, and HORIZON-CL4-2022-DIGITAL-EMERGING-01-26) and will be extended in the coming months until the reference architecture is fully developed and mapped with all projects' solution architectures

Continuum computing, more than cloud, edge and IoT

Nowadays, there are more than 43 billion devices connected to the Internet, generating, collecting, and sharing data[1]. From them, 15.14 billion are connected IoT devices, and this figure is expected to double by 2030[2].

Moving computation to the origin of the data has introduced concepts such as far edge, where data is analysed closer to its source. However, processing still needs to be shifted from the original device to others with higher computation capabilities. This situation fostered the emergence of a new paradigm, known as continuum computing, where IoT functionalities converge with the robustness and resilience of cloud and the low latencies of edge.

In this context, the concept of Continuum emerged as being more than the sum of cloud, edge and IoT functionalities, as it allows the operation of the same workflow on the three pillars. The continuum paradigm aims to break the existing technical silos moving the computation from the device to the farthest data centre, and vice versa, according to each application needs and the availability of resources.



The work initiated within the TF3 of the EUCloudEdgeIoT initiative aims to agglutinate all the knowledge coming from the research community

[1] https://www.forbes.com/sites/bernardmarr/2022/11/07/the-top-4-internet-of-things-trends-in-2023/
[2] https://explodingtopics.com/blog/number-of-iot-devices

developing a common reference architecture, validating it with different actors from the continuum value chain from standardization bodies to industry associations, aiming to position Europe ahead of the worldwide competition.

Towards a common reference architecture

The work to develop a reference architecture already gathers feedback from more than 40 ongoing research projects, addressing challenges along the continuum pillars, or layers, with a wide variety of perspectives on the compute pipeline. This situation highlighted the need of homogenization from the beginning, ensuring that all actors speak the same language.

A taxonomy is needed to homogenize concepts affecting the different pillars of the continuum, from cloud to edge to IoT, ensuring the same term means the same for different actors.

Thus, the initial step before the definition of the reference architecture is to identify those terms than can be used for cloud, edge and/or IoT and provide a common definition for them.

Following the Taxonomy Best Practice Framework[3], a faceted taxonomy has been developed and will be soon available through the EUCloudEdgeIoT portal. A faceted taxonomy is a multi-layered approach for a taxonomy, where categories do not strictly belong to one single pillar but may refer to two or more. In this case, the faceted taxonomy consists of three pillars: Cloud, Edge and IoT, plus an additional one for those terms that do not fit in any of it. Additionally, eight categories have been identified representing the technical processes to operate applications along the continuum: *Security & Privacy*, *Trust & Reputation*, *Data management*, *Resource management*, *Orchestration*, *Network*, *Monitoring & Observability*, and *Artificial Intelligence*.

According to this, the published taxonomy contains terms that belong to the continuum, while those that can be applied to one single pillar are mapped with other well-known glossaries and taxonomies like NIST taxonomy for cloud[4], LF Edge glossary for edge[5] or some ISO standards for IoT.

Following this approach all ongoing research projects were invited to participate in the identification of continuum terms in a joint workshop. An

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[3] https://www.ons.gov.uk/methodology/classificationsandstandards/taxonomybestpracticeframework
[4] https://www.nist.gov/publications/nist-cloud-computing-reference-architecture
[5] https://github.com/State-of-the-Edge/glossary/blob/master/PDFs/OpenGlossaryofEdgeComputing_2019_v2.0.pdf

initial set of terms per pillar was provided as an icebreaker. Participants provided feedback about them and added new terms based on each project perspective. Thus, all terms were discussed and agreed before being classified. The results of this activity were used as the basis for the initial terminology to be added to the taxonomy.

Cloud terms

- Public and private clouds + hybrid cloud
  - Multi-cloud management
- Orchestration of resources
  - Cluster management
  - Balancing
  - Scalability
  - Migration
- Networking (c+e+f)
  - Network slicing management
  - Software-defined networking (SDN)
  - Tunneling, Virtual Private Networks (VPN)
- Compliance assessment
- Service Level Agreements (SLA) management
- Monitoring and observability
- Security
- Trust
- Workloads deployment (c + e)
- Federation (c + e)
- Lifecycle management (c + e)
- Data storage (c + e)
- Data preservation
- Virtualization

Edge terms

- Far edge
- Data processing
  - Data privacy
  - Data curation/interoperability
  - Semantic annotation
  - Data thinning/reduction
  - Data patterns definition / discovery
  - Data consistency and availability
- Federated Learning
- Data center edge
- Telco edge
- MEC
- Fog computing
- CPU architectures variability (ARM, AMD, Intel…)
- Computational offloading
- Green computing (smart allocation(only for c+e) and smart switching)
- Discovery and mobility of edge devices
- 5G and 6G
- IoT devices discovery
- Decentralization
- Decision Support Systems (in management of control of equipment)
- Time Sensitive Networking (TSN)
- Frugal AI
- Automated monitoring system health
- Service brokerage

IoT terms

- Sensor
- Actuator
- Gateway
- Real time / Right time
- Calibration
- Device registry
- Device management
- Communication protocols (BLE, Lora, WiFi…)
- MQTT (pub/sub)
- IoT platform
- Micro processing
- Virtual object
- Digital twin
- IoT cluster
- Service (transversal to other blocks)
- Swarm computing

According to the participants,

Black terms are those belonging to one single pillar and whose definition must be included in the taxonomy.

Terms colour matching each box belong to one single pillar and their definition is well-known.

Orange terms can be used in two or more pillars; thus, these are the common ones for the continuum and must be included in the definition.

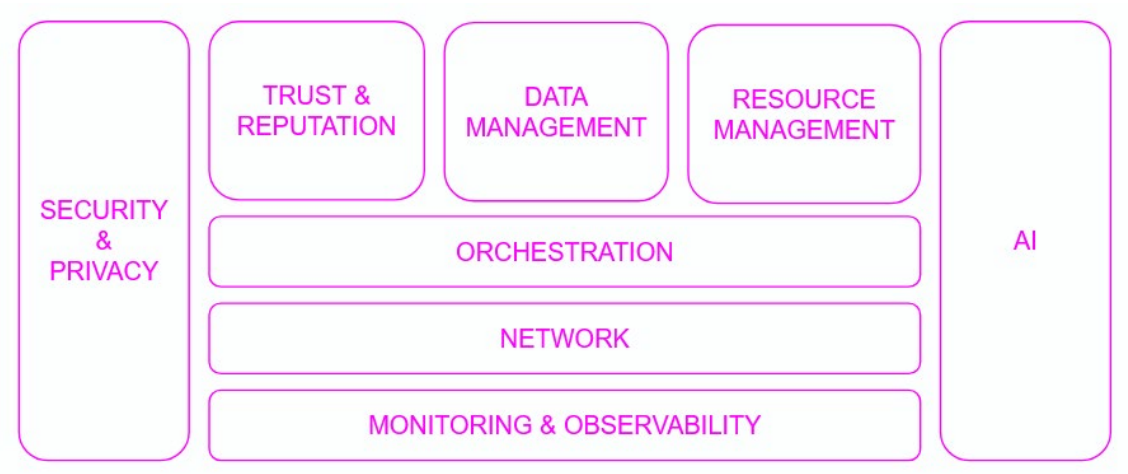
Finally, green terms are generic enough and can be added to the fourth pillar.

This continuum taxonomy is not a static document as it aims to remain useful in the coming years. Thus, it will accept requests coming from new or ongoing projects as long as they are properly justified. For example, new definitions for terms related to only one pillar will not be included as there are several existing taxonomies and standards providing them, and many of them already mapped with this continuum one. However, requests for new mappings of missing terms that are needed can be accepted.

Layered architectures support the identification of components providing the needed functionalities for further implementations.

Once the basis for the taxonomy were agreed, the next step was to identify the main building blocks of the layered architecture as a preliminary step for defining the reference one. This building blocks were collected based on the commonalities on the application architectures of each of the projects involved in the activities of the initiative. In this way, the resulting reference architecture can be implemented, or partially implemented, in ongoing and future research projects to address the requirements coming from different sectorial use cases, ranging from energy to farming or logistics, among others.

As it can be seen, the eight building blocks were included as categories in the faceted taxonomy to easily map terms within their application domain.



According to the projects involved in this activity, each building block must, at least, provide the following list of functionalities:

SECURITY & PRIVACY

Security
Privacy
Anomaly detection
Smart contracts
Authorization

TRUST & REPUTATION

Trust algorithms
Reputation mechanisms
Traceability
Accountability

DATA MANAGEMENT

Processing
Curation
Interoperability
Semantic annotation
Thinning
Patterns definition
Discovery
Consistency
Availability
Storage

RESOURCE MANAGEMENT

Federation
Ad-hoc clustering
Discovery
Registry
Communication

ORCHESTRATION

Of resources
Of services
Balancing
Scalability
Migration
Deployment
Lifecycle management
Service brokerage
Smart allocation
Smart switching
Decision Support Systems

NETWORK

Slicing
Tunneling
Mobility
5G and 6G
Time Sensitive Networking (TSN)
Programmability

MONITORING & OBSERVABILITY

Automated monitoring system health
SLA management
Compliance
Observability

Additional functionalities, when needed, will be added during the definition of the reference architecture.

ARTIFICIAL INTELLIGENCE (AI)

Frugal AI
Tiny AI
Distributed AI
Federated Learning

Conclusion and Next Steps

As it has been presented before, the procedure for developing a reference architecture consists of three major steps:

Define a common terminology to ensure all relevant stakeholders understand and use the same terms while referring to specific concepts.

Identify the common building blocks and the minimum set of functionalities to provide a simplified and easily understandable version of the architecture.

Design a reference architecture covering all aspects of the continuum.

Until now, the work related to the first two steps is finished and pending of publication while the third one will be finished and published by the end of 2023.

The reference architecture will contain not only the graphical design of the components representing functionalities or set of functionalities within each building blocks, but also workflows representing the communication between each of them. It will be further documented so it can be reused and updated according to technology evolution.

Furthermore, all projects participating in its design will provide an additional chapter mapping the reference architecture with their specific application one, showing how they are implementing the needed functionalities to cover specific market needs, coming from their use cases, while contributing to the European digital autonomy.

Additionally, the architecture will be validated within different initiatives and industry representatives to gather feedback about their specific identified challenges and gaps, and how the continuum can address them.

About EUCloudEdgeIoT initiative

The EUCloudEdgeIoT.eu initiative aims to realise a pathway for the understanding and development of the Cloud, Edge and IoT (CEI) Continuum by promoting cooperation between a wide range of research projects, developers and suppliers, business users and potential adopters of this new technological paradigm.

The EUCloudEdgeIoT initiative acts as an enabling force, to reach key outcomes:

Support the definition of the large-scale pilots envisaged by the European Commission in line with the EU Data Strategy.

Baseline common open architecture for computing continuum research projects.

Reinforce the collaboration between European public and private initiatives from cloud to edge to IoT.

Increase the awareness of the importance of open source and standards for EU digital autonomy.

Within this initiative, TF3 Architecture main goals are as follows:

Enable the architectural discussions among projects in the area of IoT/Edge and Cloud to create a continuum.

Identification of the thematic areas and building blocks.

Understanding the contribution of each project to the thematic areas, allowing the identification of cross-project synergies.

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