

DIGITAL AUTONOMY **IN THE COMPUTING CONTINUUM**

From Cloud to Edge to IoT for European Data

11 November 2021

EVENT REPORT

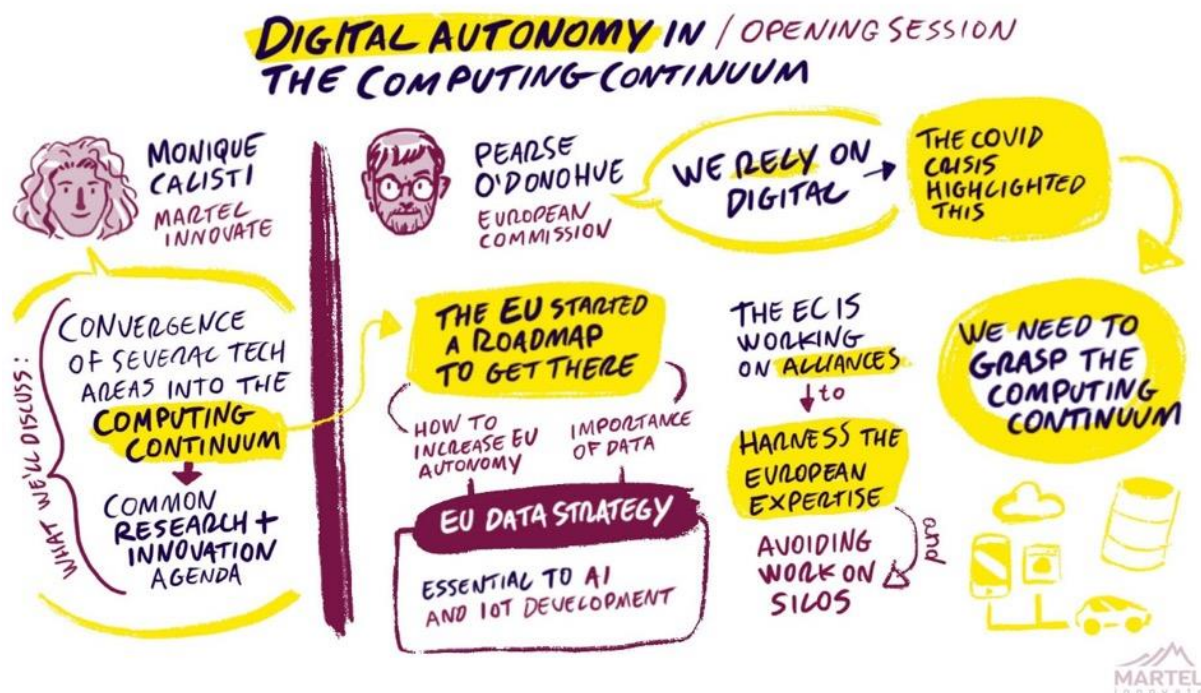


EUROPE'S JOURNEY TOWARDS THE COMPUTING CONTINUUM

Paving the Way for the Digital and Green Transitions

On 11 November 2021, the European Commission organised a virtual event titled “*Digital Autonomy in the Computing Continuum*”. The meeting gathered researchers, innovators, industrial stakeholders, SMEs/Start-ups, policy makers, standardisation experts, regulators, from relevant initiatives and related projects. The purpose was to discuss the current situation of the Cloud and IoT domains, the main trends for the near future, connections and influences with the Horizon Europe research and innovation programme and relevance in the Digital Europe Programme.

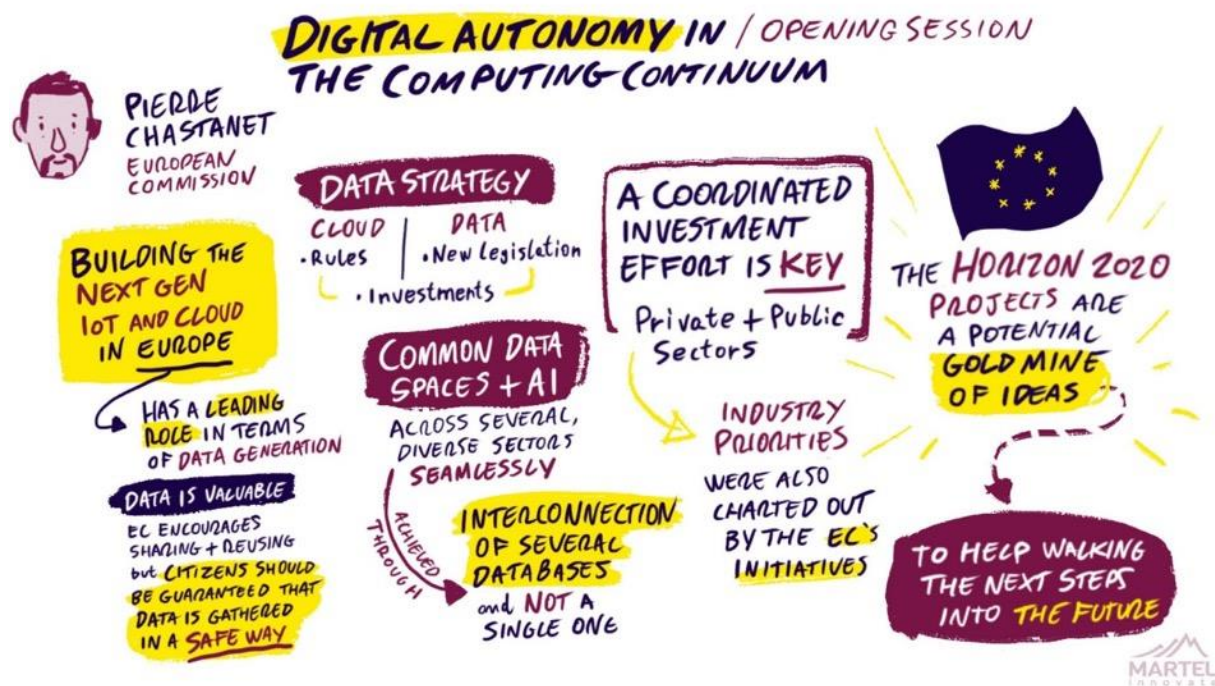
European Commission representatives opened the event presenting a new strategy ‘From Cloud to Edge to IoT for European Data’. The purpose of this strategy is to allow European companies to regain leadership in the Data Economy. Achieving Autonomy in the Computing Continuum is a cornerstone for this endeavour. The progressive convergence between Cloud Computing (CC) and the Internet of Things (IoT) is resulting in a Computing Continuum. Firstly, the multi-faceted concept of Edge Computing became to represent the middle ground between CC data centres and IoT hyper-local networks of sensors and actuators. Then a much more nuanced paradigm emerged and placed computing infrastructure on a spectrum covering from the Cloud Data Centres to Edge Nodes with many intermediate levels. High Performance Computing (HPC), Artificial Intelligence, 5G/6G networks are also part of this Continuum for which hardware and software need to be jointly considered.



Digital Autonomy has strategic importance for Europe. However, this is not an isolationist trend. The intention to participate in the global digital community is clear. Digital Autonomy for Europe means the possibility to act independently with its values. Resilient digital supply chains need to be established while driving digital innovation across all sectors of the economy, being assertive on what are the European values, safeguarding Europe's strategic interests and cooperating with the confidence of knowing that Europe has the means to follow its own path if necessary.

The emergence and continued development of the Data Economy is a key megatrend that affects not only the computing sector but also the economy as a whole. Its combination with the rise of the Computing Continuum is leading to a new landscape where Europe has a role to play. Far from trying to replicate the hyperscaler approach and business models (i.e., Google, Amazon or Microsoft), European stakeholders should seek opportunities in the data-driven transformation wave of all economic sectors. The new prospect includes the data volume increasing fivefold with 80 percent of such data produced and processed in highly distributed systems. This game changer shift is redefining the technological and business context for ICT service provisioning, data management, computing and network infrastructure for both European and non-European operators.

The EC has launched a set of coordinated initiatives on multiple levels of funding, stakeholder aggregation, industrial alliances and partnerships. The core policy document in the area is the *EU Data Strategy*. Major combined efforts currently in focus are the *Important Project of Common European Interest (IPCEI) on Next Generation Cloud* and the *Common European Data Spaces*. To add, a *European Alliance for Industrial Data, Edge and Cloud* has been launched to strengthen the position of EU industry and meet the specific requirements of EU businesses and public administrators processing sensitive categories of data. The Alliance complements the policy and project actions by ensuring stakeholders aggregation, discussion and coordinated work of relevant public and private stakeholders.

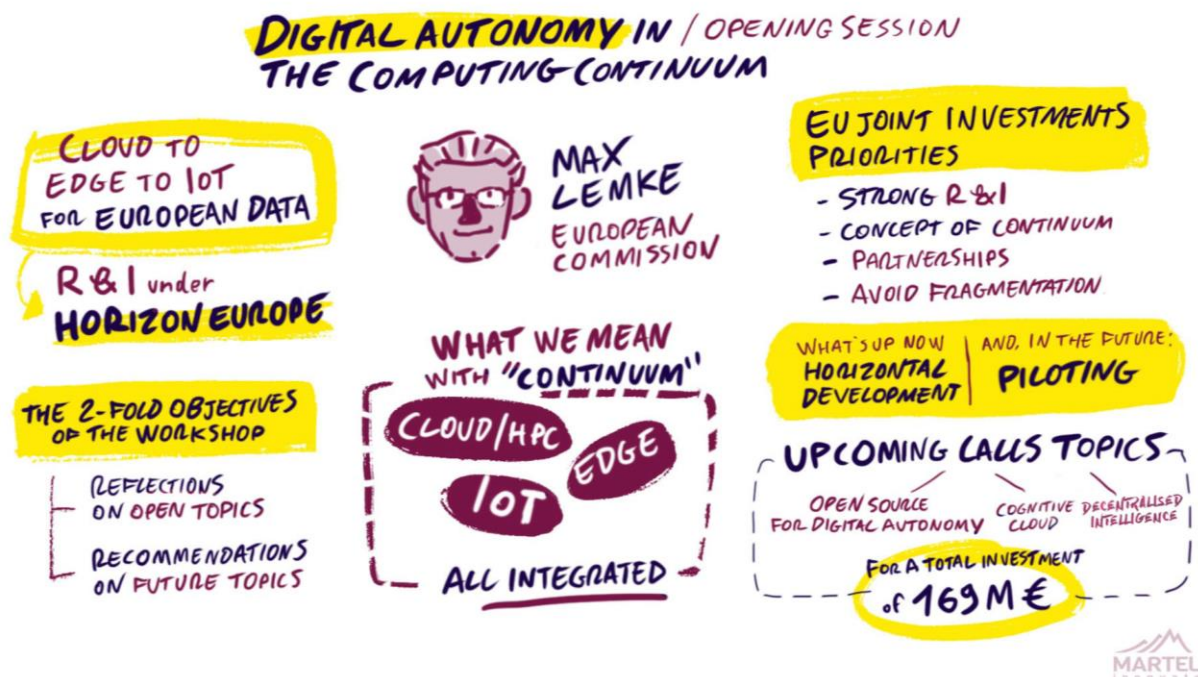


The European investment landscape in next generation Cloud/Edge computing has Horizon Europe as its main pillar. Other funding instruments include the Digital Europe Programme, the Recovery and Resilience Facility and specific national initiatives. Private investment (through Invest EU or directly from corporations) contributes to a projected total amount of more than 10 billion Euro. A comprehensive set of funding and support instruments has been set up to support the whole technology transfer chain in research, innovation, deployment, market entry and business growth.

The morning programme of the event concentrated on three sessions continuing the work on topics depicted by the HE WP 2021-22:

- **Cognitive Cloud**, connected to the 2022-DATA-01-02 topic in Cluster 4, dealing with the adoption and exploitation of Artificial Intelligence techniques to advance automation and dynamic adaptation of resource management in Cloud and Edge systems. The call for this topic will close in *April 2022*.
- **Open Source for Digital Autonomy**, related to the 2022-DIGITAL-EMERGING-01-26 topic in Cluster 4 about open-source enablers for Digital Autonomy. The call for this topic will close in *April 2022*.
- **Decentralised Intelligence and Swarm Computing**, targeting the 2022-DATA-01-03 topic in Cluster 4 about architectures, programming environments, and tools for distributed multi-device swarms and decentralized intelligence across the Computing Continuum. The call for this topic will close in *April 2022*.

The afternoon programme looked into the future by discussing possible next steps of Horizon Europe, covering the next two years of 2023-2024. That part of the Work Programme is currently under development at the European Commission. The chosen approach for the workshop was for the EC to highlight relevant directions and themes that are currently being discussed and, more importantly, to seek input from representatives of relevant industrial partnerships and alliances through presentations and panels. Finally, input and recommendations were gathered from the expert speakers and attendees. Specific attention was given to those initiatives and organisations that expressed a consolidated view (through a white paper, a strategic roadmap document, or other publication) across their membership on research challenges, technological directions, or investment priorities for the European community and institutions regarding the Computing Continuum as a strategic leadership opportunity for Europe.



COMMON THEMES ACROSS THE WORKSHOP

Despite the diversity of organisations and stakeholder groups that provided the speakers at the various sessions of the event and the complementary focuses of each session and panel, a number of themes proved relevant throughout the workshop. A well-shared common understanding of the current situation regarding Cloud/Edge/IoT Continuum emerged from the discussions with a set of promising and advisable priorities for Europe.

Europe's contribution to the global economy relies in designing safe and complex physical systems in areas like manufacturing, energy, automotive, farming et al. Workshop participants emphasised **distributed and decentralized systems and systems-of-systems as a next step in system design**. The advent of the Computing Continuum results in an unavoidable reality of multiple nodes with different computation, storage, network capabilities, belonging to or falling under the jurisdiction and shared governance of multiple principals, each with their own authority, privacy policies, and trust relationships. The traditional, application agnostic, centralized Cloud computing blueprint is and will remain the dominant topology for at least the next 3 year, even in IoT applications and systems. On the other hand, defining and providing infrastructure, services and applications in the new complex and heterogeneous environment is a very different task. Cognitive Cloud is only the beginning. Intelligence and swarm computing principles are required throughout the computing continuum to handle heterogeneous resources and diverse application requirements.

This **heterogeneity raises challenges** at multiple levels like interoperability, scalability and trust. In particular, beyond software and network architecture, the diversity of sensors, devices and edge nodes must be acknowledged. Some speakers highlighted hardware-level issues and the opportunities for specialized hardware/software codesign. The need for dynamic adaptability, orchestration and intelligence in a wider sense was underlined in several presentations. Another related theme was the relationship between Cloud/Edge/IoT Continuum, Data and Artificial Intelligence. This was present well beyond the Cognitive Cloud session and running throughout the event. Research challenges and wider issues of distributed AI, federated learning, decentralised AI model life cycle, data privacy and trust were also presented. Advances in computing and AI algorithms will spur innovation based on embedded and decentralised AI.



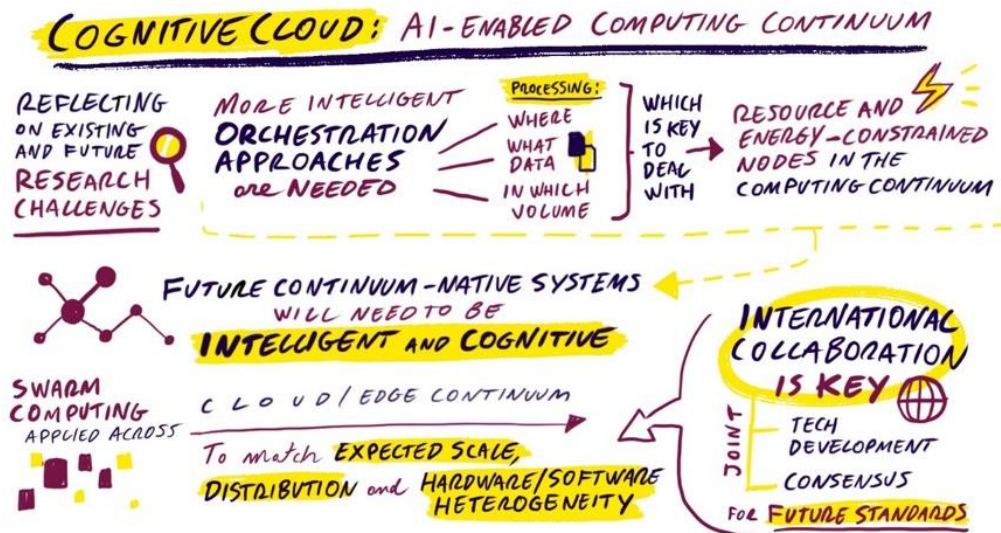
Openness was a common trait of the recommended solution approach: Open-source software and hardware, open interfaces and standards relevant for emerging hardware, data spaces, APIs, ABIs and communities

The idea of **openness** also included open interfaces and standards relevant for emerging hardware, data spaces, APIs, ABIs and communities. Several associations and alliances of European interest spoke about the vision, roadmap, and recommendations that emerged from engagement and discussions across their membership. On the European Commission side, emphasis was placed on community and ecosystem openness with, for example, the announcement of the European Alliance for Industrial Data, Edge and Cloud and the mention of its interaction with GAIA-X. The overall impression was of a plurality of voices and opinions coming together under a common strategic alignment: a practical echo of European consensus-based mode of operations stemming from the ***united in diversity*** motto.

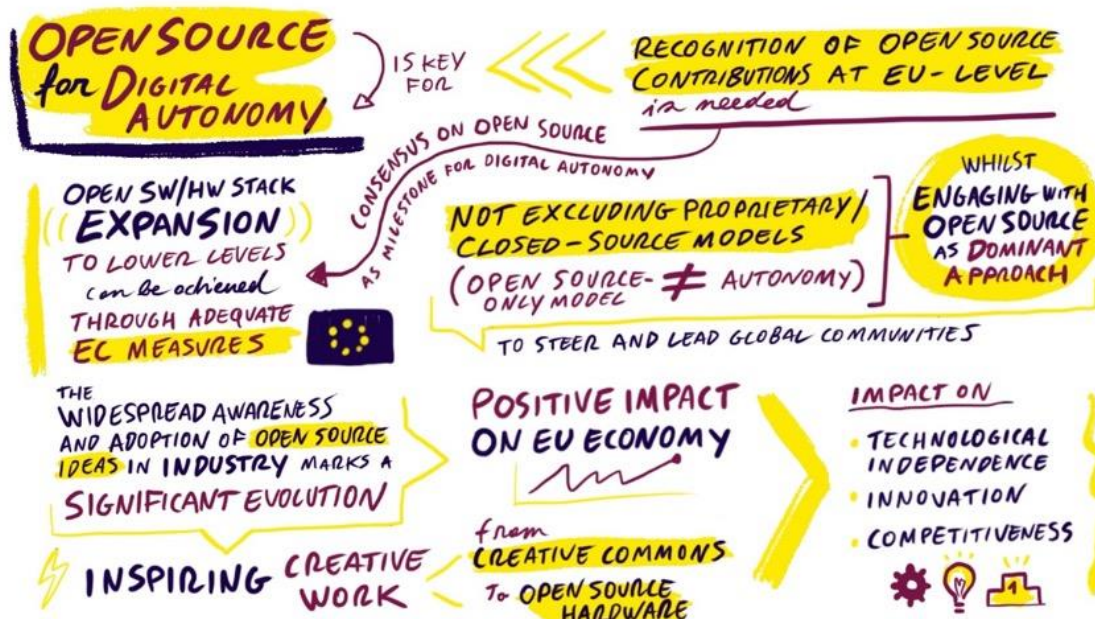
One last common trend in the workshop was the recognition of the **interplay between horizontal** (i.e., industry-agnostic) **and vertical support** (i.e., acknowledging individual industries and partially specialised for them). The implementation of core topics such as Computing Continuum or Digital Autonomy are and remain industry- and domain-independent. Horizontal themes must be complemented by specific developments in areas such as Energy or Manufacturing, in agreement with large-scale European strategic and policy objectives. True vertical take-up measures belong to deployment- and business-oriented programmes such as Digital Europe or the Connecting Europe Facility 2. Horizon Europe Cloud-Edge-IoT areas have mostly targeted horizontal calls on the 2021-2022 Work Programme. Workshop participants praised for the next WP (2023-2024) to include vertical calls on, e.g., large-scale pilots or industry-specific applications of the general Computing Continuum concepts and technologies, relying on the work done within Horizon Europe and elsewhere in the previous two years.

THE COMPUTING CONTINUUM IN HORIZON EUROPE 2021-2022 WORK PROGRAMME

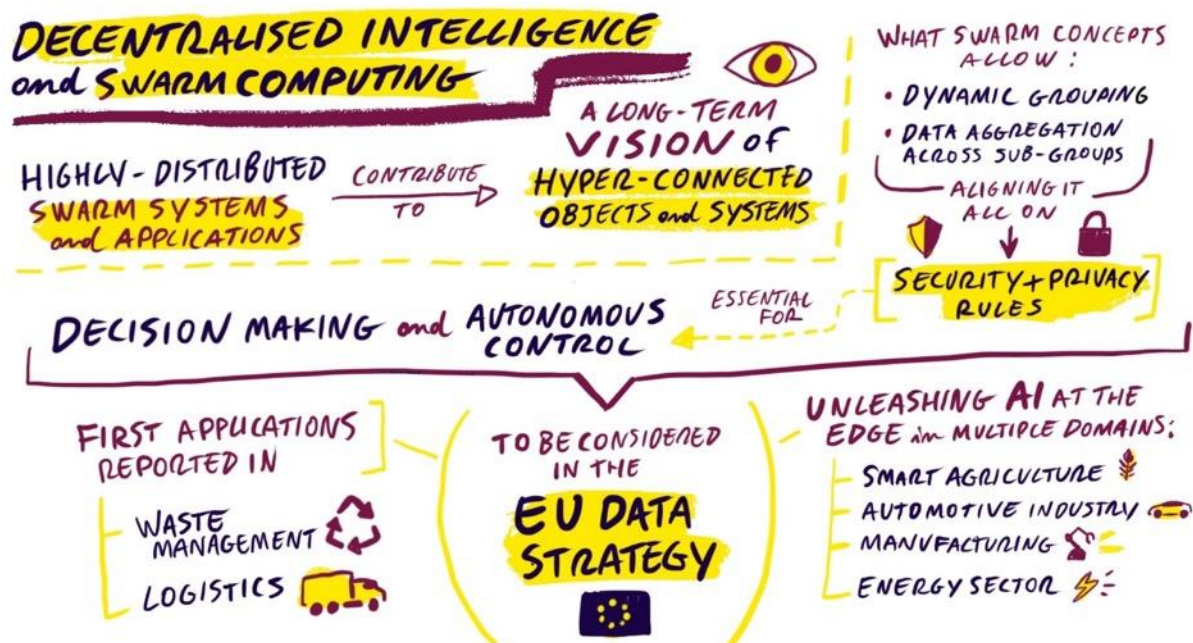
The three morning sessions were related to topics that are defined in the Work Programme. The goal was not to discuss possible project proposal ideas or approaches, but rather to reflect on the three topics (Cognitive Cloud, Environments and Tools for Decentralised Intelligence at the Edge, Open Source for Cloud-based Services), as key elements of a strategic agenda for Horizon Europe WP2023-24.



The **Cognitive Cloud** session elaborated further the existing research challenges covered in the current call and went beyond those challenges to discuss future ones. For example, more intelligent orchestration approaches are needed to effectively decide where data should be processed and in what volumes (especially important when dealing with the resource- and energy-constrained nodes at the far edge of the Computing Continuum) and intelligence will play a critical role also in the overall system adaptation, resilience and distributed control capabilities, strategies for data intensive applications and even dynamic resource migration. **All management layers of future continuum-native systems** and applications will have to exhibit **intelligent and cognitive** traits. **Swarm computing** principles should be applied in the whole cloud to edge continuum, to match the expected scale, distribution and hardware/software heterogeneity. In such a global ecosystem, **international collaboration** will be key in this area as there is a need for joint technological developments and consensus building on future standards for the next generation cloud, edge and IoT platforms.



The **Open Source for Digital Autonomy** session pointed out the relevance of Open Source Software and Hardware for the European strategic objective of achieving digital autonomy. In particular, proper recognition of Open Source contributions should be fostered at EU-level. Participants pointed out that Open Source communities have managed to develop a complete open stack from the application level to the kernel but below is still closed. The presenters invited the Commission to take adequate measures to expand the open stack to the lower levels. The session reinforced the general consensus that embracing Open Source is a key strategic milestone for Europe to achieve digital autonomy. This does not mean that proprietary or closed-source models are to be completely excluded, nor that open-source on its own guarantees digital autonomy. However, the general and dominant approach for Europe should be to fully engage with open-source projects, processes, and governance to use, to contribute, to lead and to steer global communities when relevant. Hardware architectures such as RISC-V, as well as low-level, below-operating-system software support were also discussed, in connection with strong input from industry, where a widespread awareness and adoption of Open Source marks a significant evolution of the past years. The positive impact of open-source activity on the overall economic development and prosperity was also covered in the session following the results of the study on the “impact of Open Source software and hardware on technological independence, competitiveness and innovation in the EU economy”. The workshop participant also pointed out the need for adequate EU recognition to Open Source Contributors and the need to use OS assets to regain competitiveness in the computing sector.



The **Decentralised Intelligence and Swarm Computing** session provided evidence that highly-distributed swarm systems and applications contribute to a long-term vision of hyper-connected objects and systems. However, swarm concepts provide basic tools to deal with evolving data volumes at the edge, i.e. close to the place where data is created. They allow to dynamically group objects, aggregate data across sub-groups of things and be aligned on underlying security and privacy rules, essential for decision making and autonomous control. First application like in waste management and logistics were reported, as they are not very far away, and that the EU Data Strategy should consider and include them, as they can be very effective in managing data, and providing dynamic behaviour as well as self-* autonomic properties. Presentations and discussions explored the main research challenges and directions in this topic, from conceptual characterisation of, e.g., elasticity and future cyber-physical systems, to how to unleash AI at the edge through hardware/software co-design, to many examples and use cases that highlighted the need for virtualisation built on Computing Continuum solid horizontal architectures. Multiple domains and industries were covered, such as smart agriculture, the automotive industry, the energy sector, logistics and manufacturing.

SHAPING THE CLOUD/EDGE/IoT 2023-2024 WORK PROGRAMME

The afternoon section looked for inspiration and directions for the 2023-2024 Horizon Europe Work Programme (WP) from a panel of high-level experts in data, cloud, electronic components and systems, as well as stakeholders from relevant verticals and associations to exchange views on a strategic European vision for the Computing Continuum and potential R&I priorities for Work Programme 2023-24 and beyond.



The aim of the session was to discuss topics that have been already identified by the EC, building on previous publications, consultations and interaction, and to then add considerations and recommendation from the set of diverse speakers, as well as questions and contributions from all interested attendees.

The European Commission representatives framed the session with the introduction of three pillars for the Continuum-focussed areas of the Horizon Europe 2023-2024 Work Programme: “*Open Source for Cloud/Edge Digital Autonomy*”, “*Piloting emerging Smart IoT Platforms and decentralised intelligence*”, and “*Cognitive Computing Continuum: Intelligence and automation for more efficient data processing*”. To discuss and assess these three candidate topics, as well as capture input and proposals from a diverse and representative set of European stakeholders, eight distinguished speakers were invited and suitable channels were made available for all participants to intervene, ask questions and provide comments and opinions.

Two panels of four speakers were organised: the first one (including Leo Isaac-Dognin, Director at Capgemini; Kay Bierzynski, from Infineon; Hubert Tardieu, Independent Board Member of GAIA-X; Josef Urban, from Nokia) representing industry voices, and the second one (including Monique Calisti, CEO of Martel Innovate; Koen de Bosschere, Professor at University of Ghent; Lars Nagel, CEO of the International Data Spaces Association; Ovidiu Vermesan, Chief Scientist at SINTEF) gathering representatives of associations and partnership initiatives.



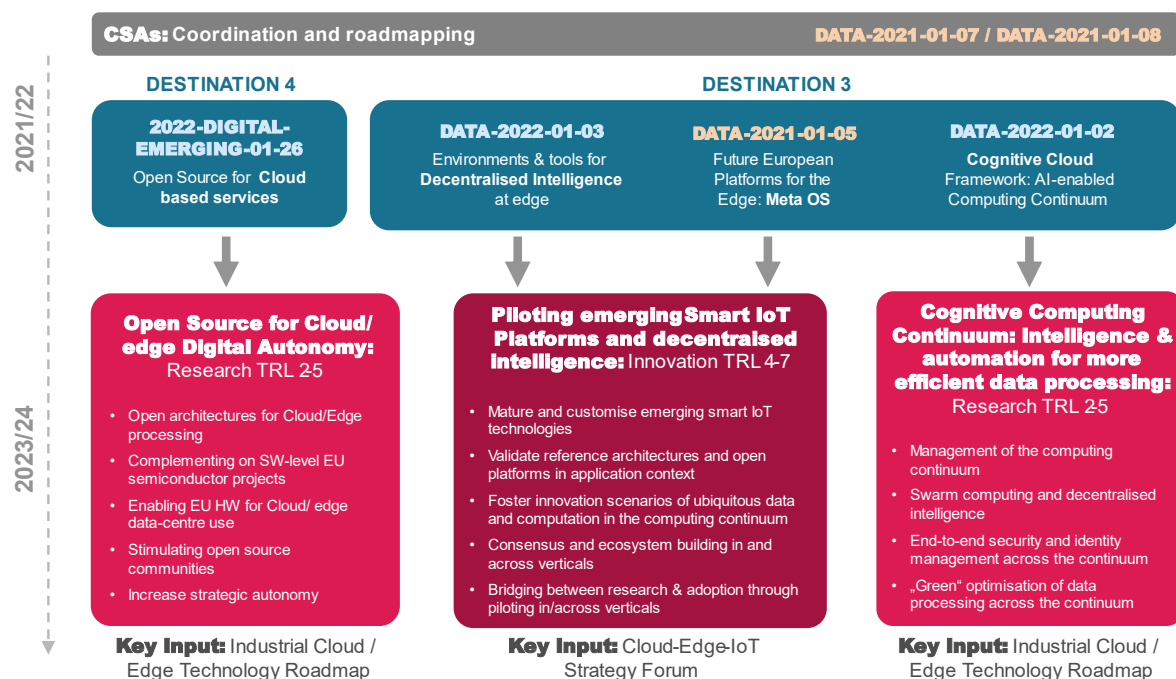
The panellists were not just speaking for themselves, not for their employer or institution; rather, they were bringing forth the common voice of a consolidated and well identified community, typically relying on a foundational document (e.g., a roadmap, a white paper, the results of a membership-wide consultation) that was prepared and published by the stakeholder group they represented.

Isaac-Dognin represented a group of 27 companies who jointly wrote a “*European industrial technology roadmap for the next generation cloud-edge offering*” report; the topics of interest include cybersecurity, interoperability, and sustainability. Kay Bierzynski, representing the European Technology Platform on Smart Systems Integration (EPoSS), one of the three industrial associations behind the ECSEL and future Key Digital Technologies (KDT) Joint Undertakings, followed up with the findings of their “*AI at the Edge*” white paper, including HW/SW codesign, environmental impact optimisation, and a wide array of use cases. Hubert Tardieu drew from use cases in the automotive sector to emphasise the need for multiple, mature ecosystems that can serve the needs of industry and citizens in various sectors, where the research outcomes from Horizon Europe projects could be effectively put to the test towards an impactful market adoption. Josef Urban, as Chairman of NESSI, concluded the first panel by pointing out the importance of interoperability and multidisciplinary research, identifying technical and non-

technical focus areas for future work and recognising Open Source as a critical enabler for digital autonomy, though not the only, exclusive way.

Monique Calisti, coordinating the EU-IoT CSA project that published the “*IoT and Edge Computing – Opportunities for Europe*” report after consultation workshop and activities, highlighted the importance of openness and the sheer diversity of scope within the Computing Continuum infrastructure. Prof. De Bosschere, coordinating the HiPEAC European network which publishes a yearly “*HiPEAC Vision*” document, presented some technical, policy, and societal recommendations including supporting open-source hardware activities, interoperability across heterogeneous hardware, and fostering a stronger innovation culture and entrepreneurial mindset across Europe. Lars Nagel laid out IDSA’s assessment that data spaces are at an important inflection point where implementation and scale-up actions gain momentum, but this needs a suitable, interoperable, distributed “soft” infrastructure and broad alliances such as the newly announced Data Spaces Business Alliance engaging IDSA, BDVA, FIWARE and GAIA-X. The second panel was complete with Ovidiu Vermesan’s statement, representing AIOTI and highlighting needs and challenges for IoT Edge research, such as large-scale integration and approaches to tackle the scalability gap at the edge.

The first of the three pillars originally put forward by the European Commission focussed on **Open Source**, which was continuously mentioned during the whole event. Open Source Software and Hardware enjoyed cross-cutting nature, going from Cloud services to Edge Computing, heterogeneous nodes, devices, hardware/software synergies and digital autonomy. Most if not all the panellist acknowledged the key role of Open Source and open standards in empowering Europe on the path to the Computing Continuum and digital autonomy: among others, EPoSS, GAIA-X, and the industry group insisted on the importance of open systems and interoperability, EU-IoT pushed for a wide definition of openness that also considers communities, and NESSI linked the value of open-source initiatives to the strength of their ecosystem. Further references to this pillar, in the area of HW/SW codesign, are to be found in the EPoSS and HiPEAC talks as well.



The second pillar considered the challenge of **mainstreaming novel architectures and approaches** across multiple application domains, once again carefully balancing the horizontal research (to drive convergence) with suitable verticalisation when appropriate (to address the current problems and needs of specific industries in a timely way). Large-scale pilots in multiple domains, combining results and technologies from previous R&I actions with state-of-the-art infrastructure and realistic requirements and use cases, were being indicated as necessary step for this mainstreaming process to succeed. This

was endorsed by the industry group with their invitation to consider end-users in the overall vision, and others such as GAIA-X and IDSA, with their stress on verticalized interoperable data spaces, or EPoSS and AIOTI with the importance and challenges of edge intelligence for a great number of industries.

The third pillar highlighted the need for **management principles** across the computing continuum. More dynamics and elasticity for groups of local nodes and systems are required. Also intelligent orchestration mechanisms from the cloud to the edge, computing resources relocation from constraint devices towards central computing centres and hybrid cloud models, anticipating the need to process large data sets and higher levels of resource dynamicity. Experts pointed to the need to **shift from cloud-native architectures and applications, representing more or less the current state of the art, to continuum-native ones**, which require further research and exploration on multiple aspects, such as end-to-end security, devices heterogeneity, energy consumption optimisation, elasticity to flexibly allocate resources and tasks, and effective languages and semantics to describe it.

The synergy among AI at the edge, dynamic resource orchestration, and distributed data generation and processing, with the critical underlying goal to support environmental impact optimization towards climate neutrality received input and endorsement from multiple angles. The industry group that wrote the *“technology roadmap for the next generation cloud-edge offering”* report underlined the importance of differentiating the various Computing Continuum segments, each at a different level of maturity, through dynamic and interoperable resource management, in order to secure European competitiveness and leadership in the flourishing emergent data economy. NESSI explicitly pointed to Cognitive Computing Continuum as an important research focus, while EPoSS mentioned “green” optimisation as an important driver of the codesign approach for AI at the edge. Moreover, the industry group placed sustainability in their absolute top priorities, possibly with combined hardware/software approaches, and AIOTI underscored the interplay of intelligent processors at the IoT edge, resource- and energy-constrained nodes, and collective behaviour of upcoming Continuum-native systems.

It is evident that for Europe to play a significant role in the emerging data economy, Europe's industry has to work in partnership – and seize the opportunities offered by managing the Computing Continuum. A common framework for sharing resources and data, monetizing the value of data via transparent cost-contract based data quality schemes and nurturing decentralised ecosystems were reported the key success factors for Europe to differentiate itself in global markets. The emerging paradigm of the Computing Continuum requires more collaboration and synchronisation across the different SRAs. To find a suitable balance between top-down and bottom-up R&I was felt essential to cope with the fact that leading cloud-service providers are quite active in this domain and to exploit the current window of opportunity. Low-TRL R&I actions would need to be combined with the need for piloting innovative solutions across the Computing Continuum systems in different application scenarios, assessing scalability, interoperability, trust and sustainability within realistic and concrete situations. Open standards related to data semantics, data exchange, ID management as well as open architectures were a baseline concept for envisaged platforms and the whole ecosystem of these future piloting initiatives, in line with what was expressed in other sessions. As a key element of the green transition, the energy footprint of computing at central places is on the rise, the trend towards edge computing may reverse the tremendous energy consumption of central computing by decentralisation and local computing.

Lastly, human potential aspects were tackled, mentioning critical enablers such as skills, training, talent, and entrepreneurship. The consultation on the 2023-2024 WP will continue with further actions, and the current timeline projects a drafting during the first half of 2022, after the calls of April, to then complete the adoption in the second half of the year.