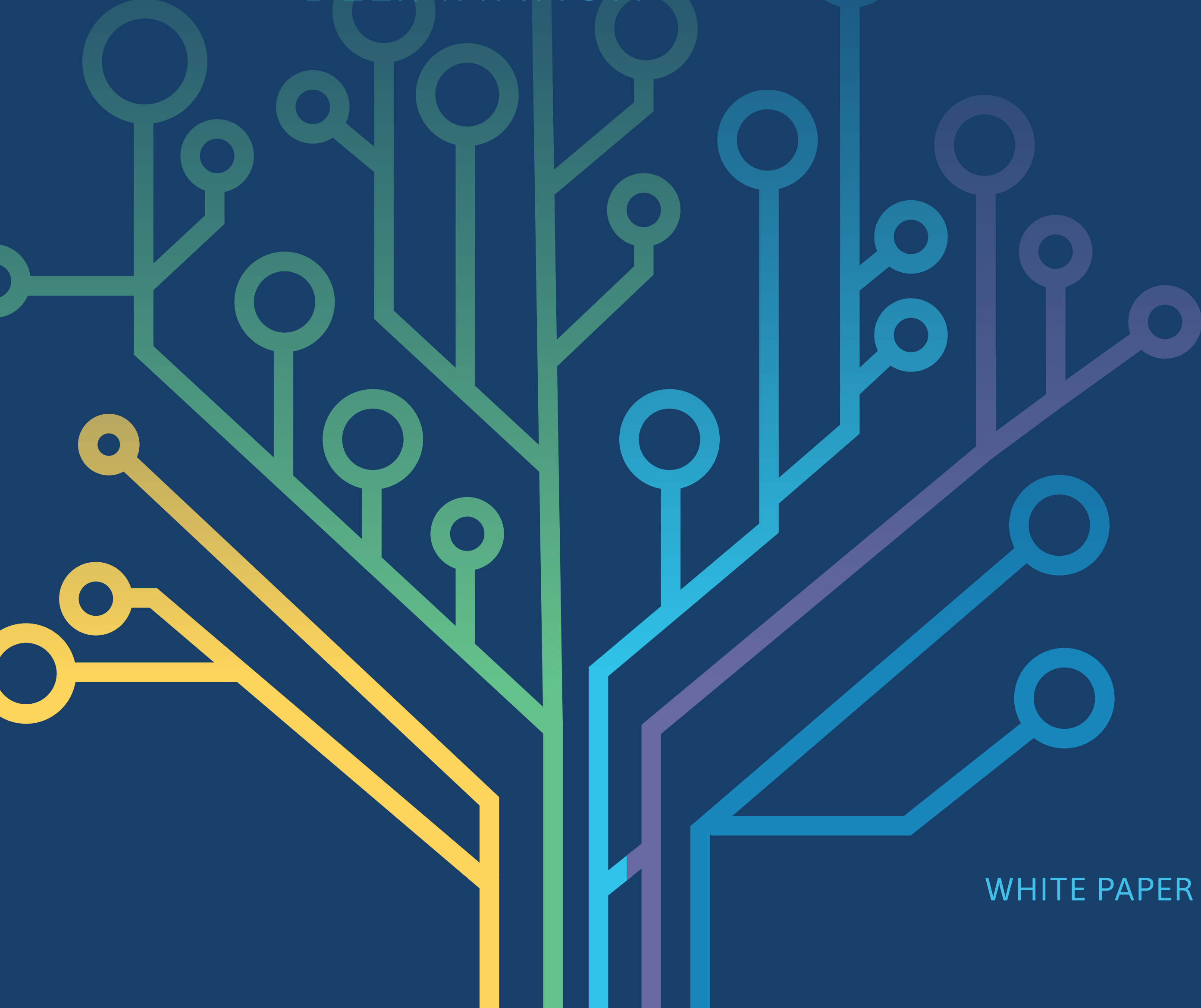
EuPro Gigant

EDGE COMPUTING IN THE EUPROGIGANT PROJECT

VISION – UNDERSTANDING – DELIMITATION



WHITE PAPER 2021

EuPro Gigant

PUBLISHING INFORMATION

Editor
Prof. Dr Matthias Weigold: PTW TU Darmstadt

Authors
Markus Weber, M. Sc. PTW TU Darmstadt
Benjamin Brockhaus, M. Sc. PTW TU Darmstadt
Stefan Dumss, M. Sc. MIVP TU Wien

Co-authors
Dr Jan Brinkhaus Brinkhaus GmbH
Melissa Brunnbauer, M. Sc. Concircle Österreich GmbH
Dr Konrad Pfadenhauer Concircle Österreich GmbH
Dipl.-Ing. Werner Kirsten Gebr. Heller Maschinenfabrik GmbH
Prof. Dr Friedrich Bleicher IFT TU Wien
Clemens Schwaiger, M. Sc. IFT TU Wien
Dipl.-Ing. Torsten Dehnert IGH Infotec AG
Dipl.-Phys. Jürgen Erstling IGH Infotec AG
Dipl.-Ing. Achim Getschmann IGH Infotec AG
Prof. Dr Manfred Grafinger MIVP TU Wien
Dr Verena Henrich Software AG

Publisher
Institute for Production Management, Technology and Machine Tools (PTW)
Technical University of Darmstadt
Otto-Berndt-Straße 2, 64287 Darmstadt
https://www.ptw.tu-darmstadt.de

Year of publication
2021

Federal Ministry
Republic of Austria
Climate Action, Environment,
Energy, Mobility,
Innovation and Technology

Supported by:
Federal Ministry
for Economic Affairs
and Climate Action
on the basis of a decision
by the German Bundestag

FFG
Promoting Innovation.

DLR-PT

EXECUTIVE SUMMARY

Within the framework of the Austrian-German model project for Gaia-X in the manufacturing industry called EuProGigant, a common data infrastructure is being designed and implemented according to the principles of Gaia-X for the value chain ecosystem. The aim of the project is to demonstrate and scale a multi-site, digitally connected manufacturing ecosystem with a resilient, data-driven and sustainable value chain to strengthen European industrial leadership. The focus of the project is connecting various machines and systems, independent of manufacturers and software or firmware versions of the control components. In addition to the requirements for a common data infrastructure with regard to IT security, safety, reliability, interface configuration for interoperability and a functioning update management, it is worth mentioning the requirements for integrated digital functions (services) of heterogeneous origin, which in the Gaia-X architecture are obtained from the data ecosystem via the federation services. The utilisation of data from production processes opens up tremendous potential for implementing industrial use cases. In the description of data value chains, high-frequency, time-synchronous data collection and processing by means of services in edge computing on the shop floor is seen as a particular driver of digital data-driven business models. The white paper lays the conceptual foundation for edge computing in the EuProGigant project and is intended to enhance the understanding of the diverse use of edge systems in production in connection with Gaia-X even beyond the scope of the project.

CONTACT DETAILS

EuProGigant – European Production Giganet for calamity avoiding self-orchestration of value chain and learning ecosystems

Pilot Factory Industry 4.0 TU Wien
Dr Claudia Schickling
Lead Management Austria
claudia.schickling@tuwien.ac.at

PTW TU Darmstadt
Prof. Dr.-Ing. Matthias Weigold
Lead Management Germany
m.weigold@ptw.tu-darmstadt.de

Markus Weber, M. Sc.
Project Coordinator
m.weber@ptw.tu-darmstadt.de

info@euprogigant.com
www.euprogigant.com

TABLE OF CONTENTS

INTRODUCTION

MOTIVATION

The consortium of the Austrian-German model project for Gaia-X in the production environment called EuProGigant sees the use of edge technology as a crucial building block of the objective described in the project proposal to build a resilient value chain and learning ecosystem.

Value creation for the consortium occurs at the producing machine or plant. Functions for enabling the production process to react to unexpected and unknown interfering factors and to keep the process stable (resilience) or to increase the speed of the value creation process are to be understood as quality features in the production environment. This requires the processing of large amounts of data from machine controls and sensors as well as a fast reaction to the information obtained – in other words, almost latency-free feedback to controls in response to local or also higher-level warning and diagnostic messages (so-called events). For the project consortium, it is crucial for the development and research on the target systems and the use cases to clarify terminology, describe general approaches and thus achieve a broad impact of the solution. Ultimately, the consortium aims to build an infrastructure and data ecosystem in which all entities of production, such as machines, plants, measuring equipment, conveyor systems, warehouses, building infrastructure, etc., are interconnected. In this way, the functional added value at the edge results in added value for the entrepreneurial value creation. The technical architecture of Gaia-X is used for cross-company and cross-location networking.

This article focuses on edge computing in the Industry 4.0 domain. The use of the proposed EuProGigant edge system is particularly relevant in the context of cyber-physical production systems (CPPS)[1] with the benefit of networking them and enabling them to communicate, exchange data and process software functions in a distributed fashion – all within a common data infrastructure. Industrial production is thus networked across companies, independent of location, flexibly and efficiently within a value chain ecosystem.

The following chapters first describe the vision of edge computing in the EuProGigant project. Chapter 3 describes the typical set-up in industrial manufacturing today as well as approaches to integrating edge computing into the manufacturing environment that have already been tested. Chapter 4 then presents the project consortium's chosen understanding of the edge system. In Chapter 5, the hardware in question is analysed and the difference to fog and cloud computing is explained.

Finally, Chapter 6 addresses the questions of liability and reassessment of CE conformity that must be answered when retrofitting edge computing solutions to existing installations.

[1] Cyber-physical production systems (CPPS): Cyber-physical systems are computers that are embedded in and control things in the physical world. Together they form a network of IT, software, mechanical and mechatronic components. In the Industry 4.0 domain, the physical things are in particular manufacturing and production equipment *[1]*.

DEFINITION OF EDGE COMPUTING

Edge computing is a widely used term in the industrial sector and is also becoming more popular in the context of the strong growth in Industrial Internet-of-Things (IIoT) applications. Edge computing is defined as the collection and processing of data with low latency because the data are needed, for example, in the near-machine environment at the edge of the company network *[2]*. Furthermore, according to the Gartner definition, edge computing is part of a distributed computing topology *[3]*.

Edge computing enables the processing of large amounts of data generated by the large number of IoT-enabled sensors and devices. In cloud computing, the transmission of large amounts of data via the internet leads to high costs, which are largely billed based on the bandwidth used. Edge computing therefore takes on the task of data compression, e.g. by generating key figures or alerts, in order to minimise data traffic into the cloud. *[2]*

The Gaia-X Association provides a definition of edge computing in the glossary on the website. Here, edge technology is described as a decentralised data architecture. Edge computing lends itself to situations where large amounts of data are generated and need to be processed. Real-time applications with latency times of a few milliseconds are also important. Cloud technologies can be connected for further data processing. *[4]*

VISION OF EDGE COMPUTING IN THE EUPROGIGANT PROJECT

The consortium describes innovative functions that will make edge computing more autonomous and intelligent in the future to promote the goals of resilience and increasing the speed of value creation in industry.

Applied to the production environment, the vision of the EuProGigant project describes edge computing with self-connection and self-orchestration functionalities. This means that the configuration of edge systems is learned and the necessary interface selection from a library of machine connection options by means of fieldbuses, other industrial computer units, sensors or the cloud is both automated and intelligent. New interfaces are automatically recognised and, according to the necessary configuration, new services for interface translation are loaded into the data connector. The data connector is a software component that enables the realisation of services for data acquisition or data output in connection with target systems. Today, a wide variety of application programming interfaces (API) are used for this purpose. Self-orchestration of the devices ensures that resources are deployed as needed and in a targeted manner, which requires networked load monitoring of the hardware and network connection. End devices should be freely and – where necessary – wirelessly positioned in the production environment and typically support integration with a machine to form a computer cluster. In the extremely visionary case, this is done via freely moving edge computer units that move like drones through production to their place of use, where they independently connect wirelessly and configure themselves for the tasks at hand. The project sees great potential in edge computing since data-driven value creation linked to innovative digital business models begins at the point of the data source and continues along the data value chain. Digital services obtained from connected data infrastructures are essential for this. These services and the underlying technical architecture of edge computing must be able to capture data at high frequency and with a clear time reference and to transfer the data into standardised data structures.

The vision shows how important new transmission technologies such as OPC UA via TSN or 5G will become in the future and which use cases can be rethought. Examples include the energy demand analysis for components or process steps, process-integrated quality management per component section and process-stabilising, near-real-time control loops. This raises the question of whether the hitherto monolithic architecture of the machine tool should be broken up to create an open machine operating within a continuously networked, flexible production environment.

EDGE COMPUTING IN THE INDUSTRIAL ENVIRONMENT

TODAY'S FACTORY NETWORKS AND THEIR ELEMENTS

Nowadays, computer units for production control (master computer) and for numerical machine control (NCU) can already be found in the industrial environment. The master computer forms a central unit in which the information from several machines involved in the value-added process converges. In addition, the master computer is used for planning and controlling production. Accordingly, all connected machines are controlled via the master computer. Central control, charging and status functions are carried out on the master computers.

The numerical control unit (NCU) forms the core of the CNC control, e.g. of processing machines. In addition to the NCU, the CNC control also includes drive controllers, a programmable logic controller (PLC) and an operating unit as a human-machine interface (HMI), as well as in some cases further computing units depending on the control architecture (e.g. PCU, TCU in Siemens SINUMERIK® systems).

These components are connected to the machine or plant in the plant network (see Figure 1). For communication between PLC, drive controllers and NCU, so-called field bus systems are used, which today are usually Ethernet-based (RTE, Real-Time Ethernet). These typically include PROFINET® and EtherCAT®, which ensure the capability of real-time information exchange for automation applications. The NCU can additionally be connected to the company network via standard Ethernet to gain access to network drives *[5]*. This is used, for example, to load machining programmes, transmit tool setting data and communicate status and error messages from machines and systems to a production control system (Manufacturing Execution System – MES) or a master computer. From an IT perspective, network topologies in factories are classically star-shaped and production systems are centrally controlled. The familiar hierarchical assignment used for this purpose is described in the automation pyramid.

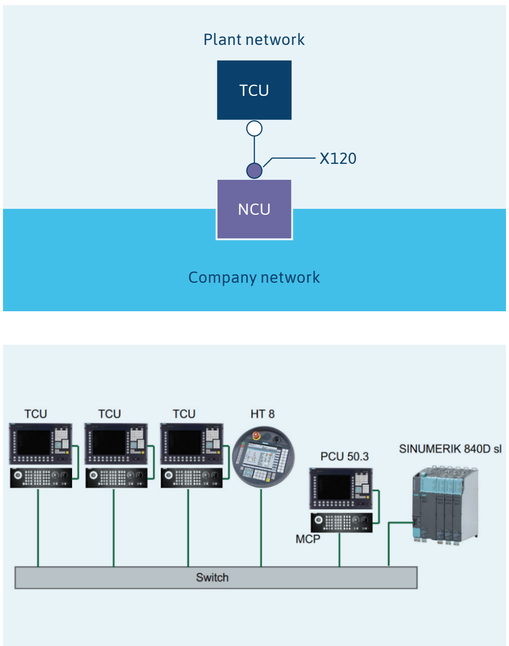


Figure 1: Differentiation into plant and company network as well as components of a SINUMERIK CNC control, image source *[5]*

In older plants and systems, the plant network is often not Ethernet-based; instead, it uses first-generation fieldbuses (e.g. PROFIBUS®) or even analogue wiring technology. A connection to a company network is often not available or not

advisable due to a lack of security updates. This gap is closed today by edge systems, which provide interfaces that are not available on a machine and thus bridge the gap between Ethernet networks and legacy systems.

Today's modern production systems are complex and require constant interaction between the physical system and its virtual representation[2]. This is necessary because, for example, customer-specific requirements are placed on products, which means that production systems have to react adaptively to this and flows of goods must be directed to specific production stations for efficient, flexible production. The principle is that products find their path through production independently depending on changing boundary conditions and that machines and systems adapt to this. This represents a fundamental change in the linking, planning and control of manufacturing and production resources. This is changing the architecture of IT systems in modern factories from classic IT network topologies to a distributed, autonomous agent system architecture.

An agent is a definable hardware and/or software unit. The agent grasps its environment and is able to react to it independently. *[6]*

A widening of perspective from just production systems to include other devices integrated into the IT infrastructure has helped establish software-defined networks (SDN) as a way to provide efficient management and programming functions. SDNs use conventional servers and hardware on which the control functions for the network can be virtualised, e.g. in containers, and scaled up as needed. The forwarding functions are separated from the control functions. *[7]*

[2] Digital twins are used in conjunction with cyber-physical production systems.

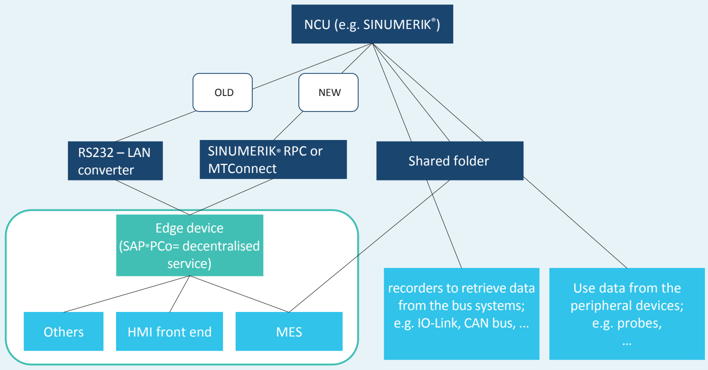


Figure 2: Data connection via a central edge device with MES and cloud connection

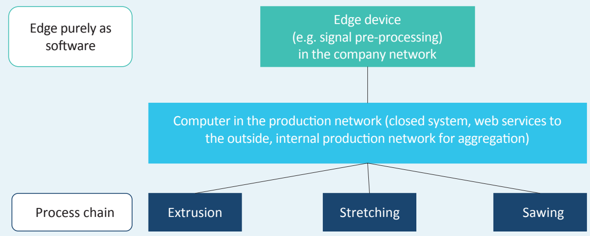


Figure 3: Edge computing at the edge of the production network

EDGE ARCHITECTURES

The consortium has already implemented various edge architectures in industrial environments. Here, a few are discussed by way of example and a conclusion is drawn with regard to general approaches and distinguishing features.

In the architecture shown in Figure 2, data retrieval of internal machine data from the NCU is done via a connector module called RPC SINUMERIK based on a remote procedure call. This module is usually implemented on the PCU and provides functions for data and file transfer. Very little data are transmitted from the SINUMERIK RPC directly in the course of the function call by the target system – here an edge device. Larger amounts of data are written to files and transferred via FTP (File Transfer Protocol) or a file system by copy and paste (shared folder) *[8]*. In the case shown, the MTConnect protocol is used as an alternative for retrieving machine data; it makes use of the machine-readable XML format to exchange data. The edge device communicates as an individual piece of hardware with the MES system, which can be queried via a web application as HMI front end, for example, and provides information for the operations on the machine. A number of services are executed locally on the edge device. The Plant Connectivity service (PCo) from SAP® is shown as an example. Further data from bus systems that are not directly available as information in the plant network can be captured via bus couplers and transmitted either independently of the edge device via a dedicated gateway or in connection with the edge device after translation to the compatible network protocol. The architecture presented here uses edge computing mainly for forwarding data to target systems by means of a hardware device with locally instantiated services acting as a decentralised computer unit close to the machine.

In Figure 3, edge computing is also used in conjunction with an ERP/MES system. In contrast to Figure 2, the edge is located centrally at the edge of the production network. This is due to the high IT security requirements and ensures that there is only one central access to the production network, which is separated from the corporate network. The production network represents the company network according to Figure 1. The central computer in the production network is a process control computer with MES software. Edge computing is software-based, e.g. on-premises, and runs on a virtual machine. It does not refer to any specific hardware. Private cloud instances can also serve as the basis for edge computing in this case. Ultimately, the application determines the tolerable latency in the exchange of information and thus the positioning of the functionalities in the network.

Figure 4 is a compilation of architectures that have in common the universal, decentralised use of edge devices as stand-alone hardware devices in machine-oriented environments with latency and big data requirements. This architecture is used when high-frequency data of dynamic applications from different sources, such as machine-internal control and drive data, analogue and digital sensor signals and pre-processed signals from external measuring systems, have to be collected, aggregated, pro-

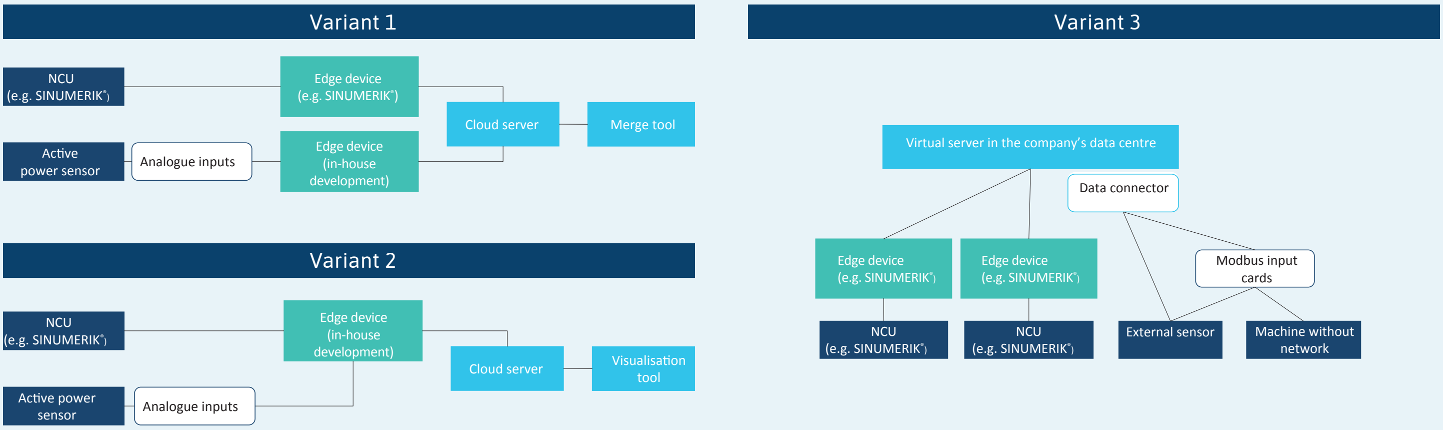


Figure 4: Practical examples of edge architectures for high-frequency data processing in the near-machine environment

cessed and sent on to target systems, e.g. via field bus (CAN, PROFIBUS®, IO-Link, etc.). Possible target systems include cloud databases, platforms with high-performance services for artificial intelligence applications and the CNC control of the machine itself. In these cases, the edge device is equipped with at least a short-term data buffer or even larger data storage solutions. In practice, some edge devices have been developed for specific tasks without provision for expansion of the devices by third parties (such as the machine operator). They consequently need to be combined with other edge devices. This quickly exhausts the available space in the machine's control cabinet so that retrofittable or separate control cabinet systems become necessary on the machine and are associated with additional costs and labour for electrical protection and documentation. Furthermore, the unused computing capacity of these special edge devices is wasted.

Figure 5 shows the case of a purely service-based understanding of edge computing. The instantiated digital services integrate functions on a computer unit according to an architecture that provides the basic functions and can be loaded and configured on an application-specific basis. Data are collected from different sources using various interfaces. Microservices in a virtualised environment using containers handle the data processing. For this purpose, depending on the application, AI engines can also be used either as an AI service for model training or as a model already trained in the specific application. Data storage is done in databases via interface translation agents. Data brokers are playing an increasingly important role in the establishment of sovereign, decentralised International Data Spaces (see reference architecture model IDSA \[9, 10]). They keep metadata available and searchable so that data objects and IT resources can be made available in the data space. Data brokers are to be understood as part of a decentralised search engine.

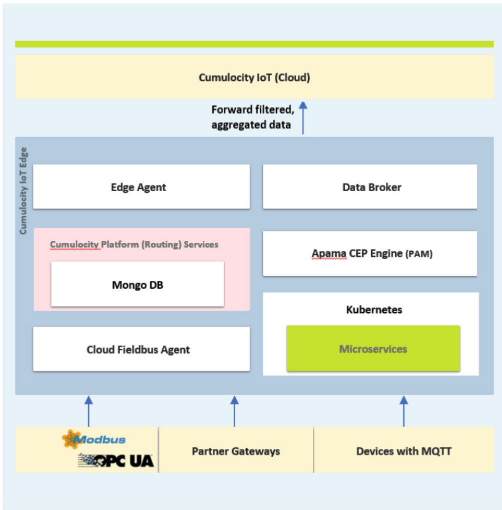


Figure 5: Edge computing as a purely software-based approach with flexible implementation in the production environment (Software AG)

EDGE COMPUTING IN A PROJECT CONTEXT

In the context of the EuProGigant project (European Production Giganet) and after compiling and discussing the information presented, the consortium has created a working definition of edge computing for the project.

The requirements are:

- Edge systems support decentralised computing operations as close as possible to the data source in order to meet a given time requirement in data transmission and data acquisition. The time requirement depends on the application.

- The edge system has an input layer, a logic layer and an output layer as its basic structure. The input layer takes over the task of data acquisition via configurable interfaces as well as the processing of data according to available, linked information models, which are themselves linked to industry-specific vocabularies. The logic layer is responsible for data handling based on the required data processing services and also for data storage, buffering and visualisation. In the Gaia-X context, the logic layer generates self-descriptions as information models and assigns them to the data. The output layer makes the data and the associated self-description available for transmission to target systems via standardised, configurable interfaces.

- The edge system enables communication with target systems, e.g. on-premises, public cloud or private cloud. The placement of the edge in the network must be determined based on IT security requirements and compliance regulations. This may differ depending on the application.

- The edge systems can take the form of edge devices or edge clouds. An edge device is a stand-alone hardware device. Edge cloud refers to computing infrastructure both in the enterprise (on-premises) and in the private cloud. The edge cloud can also place familiar services from the public cloud sector at strategic nodes close to the corporate network. This can be done in conjunction with an edge-cloud strategy, meaning that a provider's services can be implemented both in the edge and in the cloud as a software product. The functionalities of the edge – such as data processing, connectivity or applications in the field of artificial intelligence – can be situated in an appropriate place, where the greatest customer benefit arises in the given use case [11]. The functions are provided as services and are hardware-independent.

- The focus of data processing in the edge system is on increasing value creation. The process information about the value creation is merged and upgraded to new information structures so that value creation can be enhanced in bidirectional communication between the data source and the edge system. In analogy to physical value creation, data utilisation takes place along a digital data value chain.

- IIoT devices must be clearly distinguished from edge devices. An edge device differs from an IIoT device in that it offers the ability to instantiate Gaia-X services (see Fig. 6). A generic IoT device, for example, is designed only as a data source with a fixed cloud connection and gateway functionality.

The edge system is understood in the consortium as an (open source) software product that can be installed in the local network at subnetwork transition points[3] or to increase local computing capacity. The edge system is seen as a universal and flexible system that offers self-connection and self-configuration functions. It has functions for security integration and wide-ranging interface and protocol configuration and is discoverable via the Gaia-X Federated Catalogue[4] to instantiate and monitor new functions as services. For this, the edge system must be able to use the federated services (see Fig. 6) of Gaia-X. It does not interfere with any safety-related functions on the PLC or NCU due to functional isolation and security-by-design so there is no need to re-evaluate the safety of the installation.

[3] Subnetwork transitions:

- Directly at the machine:
  Transition from machine to local network;
- In the manufacturing network: Transition from corporate network to manufacturing network;
- In the corporate network:
  Transition from internet to corporate network.

[4] Both private and public catalogues are supported with either centralised or decentralised distribution

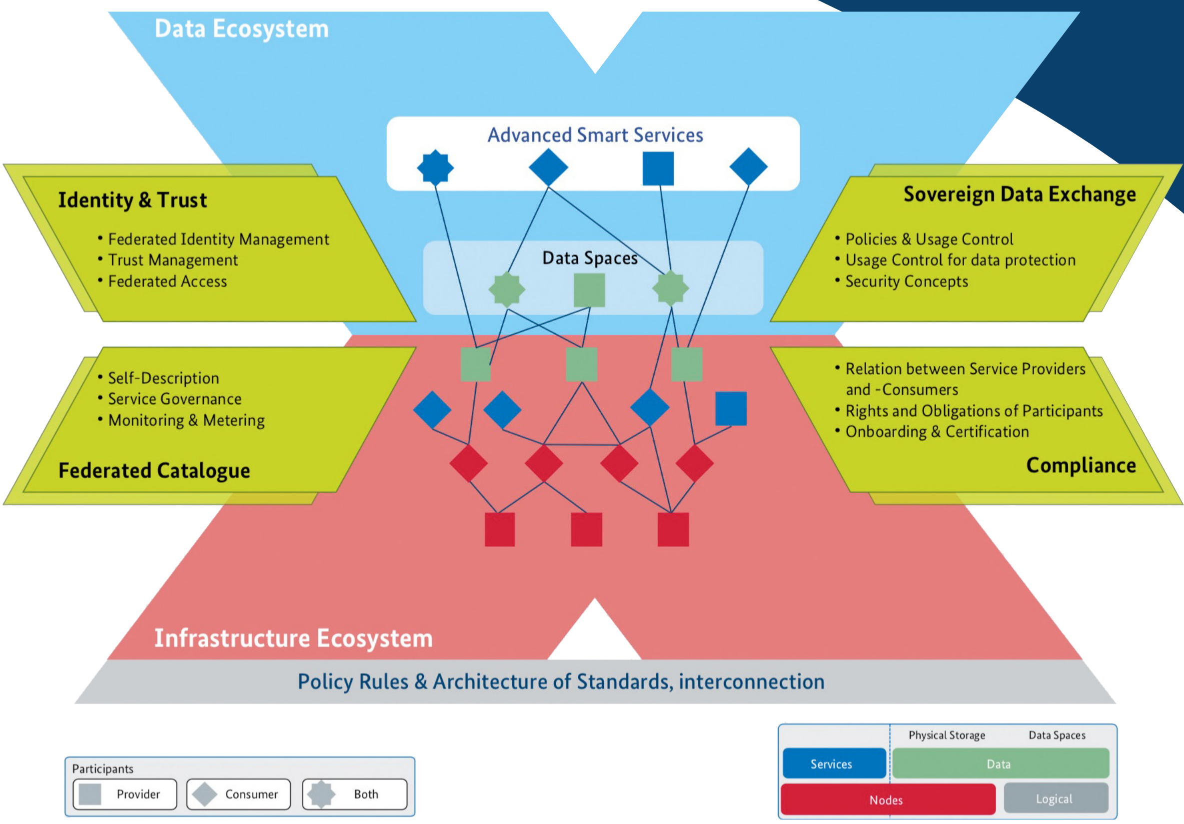


Figure 6: Federation services of Gaia-X as interface functions to orchestrate data flows between infrastructure and data ecosystem *[12]*

HARDWARE FOR THE EDGE SYSTEM

Understanding the edge system as a pure software product raises the question of the underlying hardware. Here, the edge system is supposed to be agnostic and enable the most diverse hardware classes. The hardware classes in the project context are shown in Figure 7.

The edge devices segment is made up of individual devices of different performance classes. Industrial PCs and industrial single board computers (SBC) are used in the project. On the one hand, the edge cloud includes typical clusters or local data centres, which are also frequently marketed under the terms on-premises and private cloud.

In addition, however, this is also where multiple edge devices can be connected to expand computing power or improve availability. Above this is the cloud computing segment, which refers in the context of the project to models ranging from Infrastructure-as-a-Service (IaaS) to Platform-as-a-Service (PaaS).

Since the edge system knows the performance requirements of its applications (see also Gaia-X Self-Description) and the available edge hardware also provides its services in the form of information, the positioning of the individual applications in the network can be determined automatically. This includes any repositioning that may become necessary due to disruptions or changes in service demand (“mobility of services”, i.e. service portability).

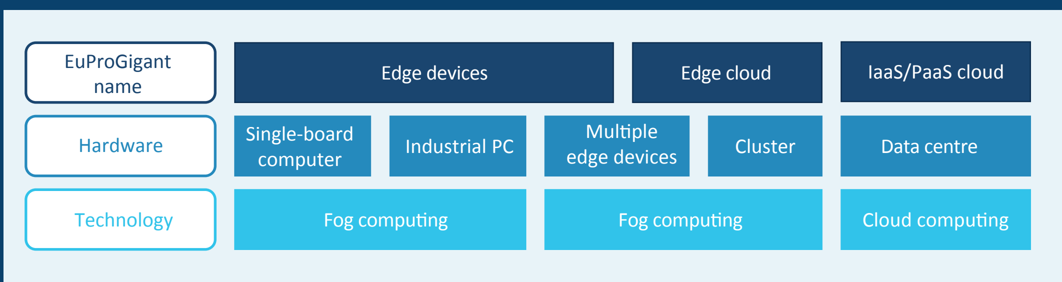


Figure 7: Hardware classes for edge systems in EuProGigant (source: PTW)

EVALUATION OF SAFETY WHEN RETROFITTING EDGE DEVICES (ACCORDING TO THE MACHINERY DIRECTIVE)

The edge system has cloud connectivity capabilities and handles tasks that are not performed on a safety-critical system (such as the NCU) due to the computing power and data volume. The devices in the plant network exclusively process a sufficient amount of data for value creation and provide safety functions for the safety-compliant operation of the machine or plant in accordance with the Machinery Directive *[13]*, such as safe motion, e-stop, safe torque off, emergency stop, emergency off. A revised version of the Machinery Directive is expected in the period 2021 – 2023 *[14]*. The conformity assessment procedure verifies the functionality of the safety functions. After evaluation, the CE mark indicates to the operator of a machine that it conforms to the standard *[15]*. The use of edge systems in connection with control units on machines and plants is considered critical if safety signals are influenced by them. In order to avoid a reassessment of conformity after installation of an edge system, it must be demonstrated that the change is not substantial as defined in the Machinery Directive. The question to be clarified is whether new hazards have arisen as a result of the installation or whether an existing risk has increased. TÜV Süd writes that in cases of retrofits to machine controls, the majority do not constitute substantial changes *[15]*. In addition to the Machinery Directive, detailed requirements can also be found in the paper "Substantial Modification of Machinery" published by the Federal Ministry of Labour and Social Affairs *[16]*. It is essential that existing safety parameters remain unaffected by the integration of edge systems and that no safety-related control signals are processed. In this case, according to TÜV SÜD, a reassessment of conformity to the standard is not necessary *[15]*. After a machine or plant has been modernised, it is of great importance that the documentation be kept up to date, including circuit diagrams, construction drawings, operating instructions and risk assessments. An important exception applies in that special services can be installed for data provision on the NCU or the PLC that take up computing capacity and could potentially hinder safety-relevant functions of the device.

LITERATURE

[1] Plattform Industrie 4.0 Österreich, Cyber-physische Systeme. [Online]. Available at: https://plattformindustrie40.at/forschung-entwicklung-innovation/cyber-physische-systeme/ (Accessed: 1 November 2021).

[2] K. Shaw, Wie funktioniert Edge Computing? [Online]. Available at: https://www.computerwoche.de/a/was-ist-edge-computing,3550237 (Accessed: 6 May 2021).

[3] Gartner, Gartner Glossary: Edge Computing. [Online]. Available at: https://www.gartner.com/en/information-technology/glossary/edge-computing (Accessed: 6 May 2021).

[4] Federal Ministry for Economic Affairs and Energy, GAIA-X Glossary: Edge Computing. [Online]. Available at: https://www.data-infrastructure.eu/SiteGlobals/GAIAX/Forms/Listen/Glossar/Glossar_Formular.html?resourceId=1737836&input_=1839500&pageLocale=en&titlePrefix=E#form-1737836 (Accessed: 6 May 2021).

[5] Siemens, SINUMERIK: SINUMERIK 840D sl Bedienkomponenten und Vernetzung (IM5). Inbetriebnahmehandbuch. [Online]. Available at: https://cache.industry.siemens.com/dl/files/279/53878279/att_40779/v1/IM5_de_de-DE.pdf (Accessed: 6 May 2021).

[6] Lüder, Arndt and Vogel-Heuser, Birgit, "Elektronische Datenverarbeitung - Agentenbasiertes Steuern" in Dubbel Taschenbuch für den Maschinenbau 2: Anwendungen, Bender, Beate and Göhlich, Dietmar, ed., Berlin, Heidelberg: Springer Berlin Heidelberg, 2020, pp. 143–150, doi: 10.1007/978-3-662-59713-2_7.

[7] Red Hat, Was ist Software-Defined Networking? Infrastruktur. [Online]. Available at: https://www.redhat.com/de/topics/hyperconverged-infrastructure/what-is-software-defined-networking (Accessed: 2 November 2021).

[8] Siemens, SINUMERIK: SINUMERIK Integrate RPC SINUMERIK. Projektierungshandbuch. [Online]. Available at: https://cache.industry.siemens.com/dl/files/109/109756109/att_942846/v1/RPC_config_man_0218_de-DE.pdf (Accessed: 6 May 2021).

[9] International Data Spaces Association, A trustworthy architecture for the data economy. IDS Infographic. [Online]. Available at: https://internationaldataspaces.org/wp-content/uploads/dlm_uploads/IDSA-Infografik-English.pdf (Accessed: 6 May 2021).

[10] Boris Otto and Anna Maria Schleimer, "GAIA-X and IDS: Position Paper". [Online]. Available at: https://internationaldataspaces.org/wp-content/uploads/IDSA-Position-Paper-GAIA-X-and-IDS.pdf

[11] Intel Deutschland GmbH, Eine Edge-Cloud bringt Sie näher an Ihre Business-Intelligence heran. [Online]. Available at: https://www.intel.de/content/www/de/de/edge-computing/edge-cloud.html#:~:text=Eine%20Edge%2DCloud%2DStrategie%20positioniert,%2DCloud%2DDiensten%20%C3%A4hnlich%20ist. (Accessed: 6 May 2021).

[12] BMWi, "GAIA-X: Technical Architecture", June 2020. [Online]. Available at: https://www.bmwi.de/Redaktion/EN/Publikationen/gaia-x-technical-architecture.html. Accessed: 4 January 2021.

[13] Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC, 2006. [Online]. Available at: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32006L0042

[14] TÜV SÜD, Maschinenrichtlinie 2006/42/EG einfach erklärt. [Online]. Available at: https://www.tuvsud.com/de-de/indust-re/maschinensicherheit-info/maschinenrichtlinie (Accessed: 6 May 2021).

[15] TÜV SÜD Industrie Service GmbH, Maschinen ändern: Retrofit EG-konform umsetzen. [Online]. Available at: https://www.tuvsud.com/de-de/-/media/de/industry-service/pdf/netinform/maschinen-ndern---retrofit-eg-konform-umsetzen.pdf (Accessed: 6 May 2021).

[16] Federal Ministry of Labour and Social Affairs, "Interpretation Paper on Substantial Modification of Machinery", Joint Ministerial Gazette (GMBl), No. 10, pp. 183–186, 2015. [Online]. Available at: https://www.bmas.de/SharedDocs/Downloads/DE/Arbeitsschutz/interpretationspapier-veraenderung-maschinen.pdf;jsessionid=3EDFB891D9BA753CEF581B3DB2051142.delivery1-replication?__blob=publicationFile&v=1

ABOUT EUPROGIGANT

EuProGigant stands for "European Production Giganet for calamity avoiding self-orchestration of value chain and learning ecosystems". The binational project commenced on 1 March 2021 and will run for four years. The aim is to build a cross-location, digitally networked production ecosystem. The framework is provided by the Austrian programme "RTI Offensive Big Data in Production" of the Research Promotion Agency (FFG) on behalf of the Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation, and Technology (BMK) and the German programme "Development of Digital Technologies" of the Federal Ministry for Economic Affairs and Climate Action (BMWK). EuProGigant is a registered EU-wide trademark in word and image of TU Vienna and TU Darmstadt.

EuPro Gigant

Vienna University of Technology
Karlsplatz 13, 1040 Vienna
Telephone: +43 1 58801 0
ATU37675002

Technical University of Darmstadt
Karolinenplatz 5, 64289 Darmstadt
Telephone: +49 6151 16-0

Federal Ministry
Republic of Austria
Climate Action, Environment, Energy, Mobility, Innovation and Technology

Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

FFG
Promoting Innovation.

DLR-PT