Strategic Research, Innovation and Deployment Agenda

AI, Data and Robotics Partnership

Third release
September 2020

A joint initiative by

BDV Big Data Value Association · CLAIRE · ellis European Laboratory for Learning and Intelligent Systems · EurAi · eu ROBOTICS

Artificial Intelligence – a real business driver for Europe?

Artificial Intelligence (AI), Data and **Robotics** will create new opportunities, transform many if not all verticals and ultimately shift the balance of power in the shortest possible time.

AI, Data and Robotics combined will be the core driver of innovation, productivity and economic growth. Together they can be used to solve the greatest challenges we face: Environmental sustainability; energy, food and water security; and improving health and quality of life.

Europe can and must be the pacemaker worldwide!

In Europe we must not be shy or afraid. We have our strengths – which we should not neglect. We should use them!

Our strengths are our excellent research networks, our well-established companies that are world market leaders in several major verticals, our growing startup communities and, not to forget, our European values.

Of course, we must be open and accept the challenges and worldwide competition.

To leverage our strength, we brought major European activities for **AI (Claire, Ellis, EurAI), Data (BDVA)** and **Robotics (euRobotics)** into a **Partnership** and setup cooperation with other major European and regional initiatives.

This **Partnership** is the European focal point for AI, Data and Robotics. Europe has all the expertise needed to progress rapidly in the deployment of these technologies, but it needs to direct energy towards building a coherent infrastructure to stimulate deployment and adoption, build up an effective innovation ecosystem and drive excellent research.

This **Partnership** will federate and cohere the communities that underpin European AI, Data and Robotics. It will stimulate private investment and orient public funding to address the key challenges. Collaboration within the Partnership will deliver Europe's vision for a human centric and trustworthy use of AI, Data and Robotics.

It is a pleasure for us to present you this paper – the **Strategic Research, Innovation and Deployment Agenda**!

This paper results from the joint work of BDVA, Claire, Ellis, EurAI and euRobotics colleagues. It includes hundreds of contributions collected in consultations with stakeholders, member states, associations, and individuals.

Many thanks to all contributors!

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Artificial intelligence will transform many if not all branches of economic activity, and Europe must get its act together to remain globally competitive. At Philips, we are convinced that AI will in particular be one of the key enablers of the digital transformation of healthcare – which is urgently needed in order to be able to contain costs and assure adequate access to care for all. This in the face of a rise of chronic conditions, an ageing population, and a rapidly increasing shortage of qualified healthcare professionals. The application of AI will be key to be able to turn personal health and contextual data from ubiquitous connected medical devices at the hospital and in the home into actionable insights – and then into the right actions. It is urgently needed to boost the adoption of technologies like advanced machine learning, natural language processing, chat bots, semantic reasoning, computer vision, and the patient digital twin to healthcare systems. Europe must be at the forefront of developments in these fields – closely linked to relevant domain knowledge like biomedical sciences, medical imaging, precision diagnosis, monitoring, image guided minimally invasive therapy, clinical informatics, and population health management. To avoid fragmentation of efforts, and to be able to develop scalable solutions based on the responsible application of AI to healthcare across Europe, the establishment of a large public private partnership in Europe will be of crucial importance for the EU economy and the health and wellbeing of its people.

Dr. Henk van Houten

Chief Technology Officer, Philips

Artificial Intelligence (AI) is a powerful technology, getting more capable every year. The challenge is for industry to harness that power. The AI PPP will help achieve that by bringing together expertise in algorithms, sensors and robotics, and addressing the realities of regulation and the need to build partnerships. The AI PPP is an exciting development for the mobilisation of AI in industry.

Professor Andrew Blake

Former Laboratory Director of Microsoft Research Cambridge and former Director of Alan Turing Institute and member of ELLIS

Robotics and Artificial Intelligence are key enablers for offering solutions to many of our societal challenges, from demographic changes to sustainable production and healthy living. KUKA supports the foundation of a public-private partnership in AI to drive and accelerate innovation in robot-based automation across all market domains by setting clear impact-driven objectives and establishing a vivid ecosystem of researchers, enterprises and investors to achieve these objectives.

Peter Mohnen

CEO KUKA AG

The European approach to artificial intelligence should be based on European values. Europe can become a global leader in ethical, inclusive, privacy protecting artificial intelligence. The AI PPP is meant to create a vibrant AI eco-system that all Europeans can benefit from. It is especially important for Europe to ensure that AI is multilingual, that it understands and speaks all the languages that Europeans speak, and that it can extract knowledge out of the vast amounts of multilingual data in written and spoken forms. Small and big enterprises and language communities should be supported with tools, data, know-how and, the skills to fully embrace the potential of AI.

Dr. Andrejs Vasiļjevs

Executive Chairman, Tilde

Artificial intelligence will shift the balance of power in the shortest possible time. Here we have to see how we can assert and expand our position very quickly. Europe can and must be the pacemaker(s) for Industrial AI – where in Europe the domain knowledge is available and we have a powerful network between SMEs, big companies, research institutes and government. We need from industrial perspective fast-track programs to exploit the opportunities offered by applications of artificial intelligence for industrial and societal benefit in alignment with our European ethical principles! Therefore I very much appreciate and support the establishment of a European Public-Private Partnership on AI as a central hub to collaborate with other initiatives especially inside Europe and with all the member states … because we have one common goal: we have to boost Artificial Intelligence in Europe!

Dr. Roland Busch

Deputy CEO, CTO, CHRO and Member of the Managing Board of Siemens AG

As European enterprises evolve into learning enterprises, they will develop an evidence-based culture where the information at hand shapes decision making. Data scientists, working with data engineers, architects, and business experts, will increasingly be able to combine knowledge of the algorithms with an understanding of functional goals. These enterprises will fully instrument their processes, physical assets, and products to unlock the value from dormant or dark data, to harness crowd-sourced intelligence, to use digital twins for simulation, to track social networks, and to understand customer experiences. They will employ AI, business intelligence, data intelligence, and other technologies throughout the organization. Those that can achieve this economy of intelligence will have a competitive advantage just as those organizations in the past that achieved economies of scale and scope had an advantage over peers. At IDC, we predict that over the next four to five years enterprises that invest in these capabilities effectively will experience a substantial increase in knowledge worker productivity, resulting in shorter reaction times, increased product innovation, and improved customer satisfaction, in turn leading to sustainable market share leadership in their industry. We at IDC look forward working with the PPP community to research and develop the economy of intelligence in Europe.

Steven Frantzen

Senior VP IDC EMEA Region

'It was the best of times, it was the worst of times'. We have entered an era of unprecedented characteristics that can prepare the path for a truly informed and sustainable development of our societies in a changing and challenging environment. The characteristics of today are the exponentially growing amount of geospatial data and the remarkable technological progress. Artificial intelligence is the only viable way for a timely extraction of added value information from the plethora of data sources becoming available and that can provide an understanding of our past and the outline of our future environment. As Europe is the leader of the biggest Earth Observation Program ever – the Copernicus program - it only strengthens the idea that Europe must be a lighthouse for Artificial Intelligence developments for the Earth Observation domain. Thus, I strongly support the establishment of a European Public-Private Partnership on AI, seeing it as a requisite to set the framework for a 'best of times'.

Dr. Florin Serban

CEO Terrasigna

__Artificial intelligence__ (AI) is a core driver of innovation, productivity and economic growth. It enables the __"Intelligent Enterprise"__ through human-machine collaboration, allowing humans to focus on higher-value work. Europe has largely contributed to the rise and upswing of AI and should keep a central role in shaping the technology's future. Broad and fast adoption of AI and the support for digital technologies by SMEs will be crucial for future European competitiveness. The public sector could become a role model for AI deployment, demonstrating that it yields tangible benefits for citizens. Europe should establish large-scale AI research and innovation clusters that are on eye-level with those in the United States and China. At the same time, AI developments need to respect European values and legal standards. This will help to address critical societal challenges and support broad social acceptance on which the success of AI in Europe depends. A European vision for human-centric AI that aims at European prosperity will be an important step in this direction. With our vision of the Intelligent Enterprise, and as a market leader in enterprise software applications, SAP supports the __European AI Public-Private Partnership__.

Juergen Mueller

Chief Technology Officer and Executive Board Member at SAP SE

CLAIRE, the European Confederation of Laboratories for Artificial Intelligence Research in Europe, is an initiative by the European AI community that seeks to strengthen European excellence in AI research and innovation. CLAIRE supports the establishment of a cPPP with the objective of increasing the rate of developing, deploying and adopting advanced technologies from the broad field of Artificial Intelligence across European industries. A PPP that seeks to increase value-creating collaboration between advanced research, universities and industry is of great importance for the development of the AI- and AI-based industry in Europe.

Dr. Morten Irgens

Oslo Metropolitan University, Kristiania University College, CLAIRE's Executve Board

Artificial Intelligence is a major strategic priority for Europe. An AI Public-Private Partnership would provide an important mechanism for bringing key stakeholders from the research and industry communities together. The European Artificial Intelligence Association was established in 1982 and is one of the oldest and largest AI associations in the world. We very much welcome an opportunity to collaborate with euRobotics and the BDVA in bringing many key capabilities within the European eco-system together to address the opportunities and challenges presented by AI.

Professor Barry O'Sullivan

President of the European AI Association

One of the key issues for the future is leveraging IoT data and enabling cross-sectoral "data marketplaces", providing true interoperability, lowering regulation barriers, etc. to unlock the full potential of innovation IoT-based applications. Advancing in the convergence of IoT with other enabling technologies such as next-generation connectivity, AI, edge computing, is the key to sustain and extend European leadership in the digital innovation space. Our collaboration and support to this SRIDA document is one of the important steps in proofing the concept and ensuring it is implemented in Europe.

Natalie Samovich

AIOTI Steering Board Chairwoman and WG Smart Energy Chairwoman

Today the power of big data leads services, products and processes to a higher level of "intelligence", towards a new generation of intelligent solutions designed to improve the quality of our time and regenerate energies by identifying and anticipating needs, providing personalized services, foreseeing phenomena and optimizing the resources available ... all this strictly in line with trustworthy and ethical principles. Private industrial and research investments are already in place. In this context, a European Public-Private Partnership on AI is of extreme value to guarantee the proper alignment of forces that over the next few years will massively bring intelligent systems in everyday life. Europe cannot miss the possibility to be disruptive in the development and adoption of leading Artificial Intelligence solutions ... to be adopted inside and outside Europe.

Orazio Viele

CTO Engineering Ingegneria Informatica S.p.A.

AI for Industry is still open and Europe has a realistic chance to shape its future!
AI for Industry uses Industrial Data which is generated by Industrial processes.
AI for Industry is the natural next step after the adoption of Big Data and Analytics by Industry.
AI for Industry needs to show measurable results which can be endorsed by businesses.
AI for Industry requires scarce industrial resources to build the model and to label the results.

Therefore we very much appreciate the European activities towards AI Public Private Partnership which will give us the central access point for AI in strong and inclusive collaboration with all AI activities in Europe!

Hubert Tardieu

CEO Advisor, Atos SE

Europe has the fundamentals to be a leader within artificial intelligence, data analytics and robotics in a way the benefit both industry and society. However, the global competition is fierce, and leadership requires that the public and private side jointly invest massively and wisely into the new opportunities to create business opportunities, develop digital skills and to keep and attract new talent. European Public-Private Partnership on AI (AI-PPP) would be a central instrument to pool together the resources needed and to network big companies, SMEs, start-ups with research institutes, universities and government

Dr. Tua Huomo

Executive Vice President, Knowledge Intensive Products and Services, VTT Technical Research Centre of Finland Ltd.

Artificial Intelligence is key to the development of the economy and society. Its transversal nature favors its incorporation to all sectors and requires new ecosystems of public-private partnerships and new agile instruments that promote the transfer of knowledge from the university and research centers to the private sector and society. In this sense, new agile European Public-Private Partnership on AI, the network of European AI Digital Innovation Hubs and AI technology centers between academy and industry are essential to develop an European economy based on artificial intelligence that is aligned with the European ethical principles.

Prof. Asunción Gómez-Pérez

Vice-Rector for Research, Innovation and Doctoral Studies of the UPM

Machine Learning and Artificial intelligence together with Data will drive the next generation of applications in industry and the public sector and provide a shortcut to solving the development goals put forward by the UN. To meet and exceed the demand for competence and solutions, Europe must increase its investments in education and applied research. The establishment of a European Public-Private Partnership on AI is a powerful tool to make this happen when integrated into national initiatives like AI at RISE in Sweden.

Dr. Pia Sandvik

CEO, Research Institutes of Sweden

Having been the first European sector employer organisation to address the effects digitalisation has on the world of work in a structured way, it is Ceemet's believe that digitalisation, and all its forms such as AI, has to be human centric. It is not a new insight that skills, right-skilling, training, including of teachers, adapted curricula in education and -vocational- training are vital for rolling out digitalisation across Europe by creating competence, confidence and trust, so that AI, robotics, and data can fully unleash their potential to the good in a competitive Europe, that has chosen to underscore an ethical approach to AI, and beyond. Fear is not a good guide and whereas AI can be compared with a black box, it is careless to play with fears that more jobs will be lost due to digitalisation than there would be created. Therefore, I appreciate this industry- and research-driven initiative by euRobotics and BDVA to address these issues.

Uwe Combüchen

Director General, Ceemet

Autonomous AI systems must, just like humans, function within legal and ethical frameworks. Due to individual and cultural differences in those frameworks, you cannot leave that to the designers, suppliers or owners. This is a task for our European governments. But if these governments only prescribe what AI can and must do, the potential of AI will remain limited to what people can already do. The development of reasoning systems is a challenge for science and industry. Specifying goals and quantifying utility - what is the value of the different outcomes? - is a task for the government. A European AI PPP can play an important role in the necessary corporation between governments, industry and research and technology organizations. Europe is well positioned in terms of system thinking, multidisciplinary approach and innovation to achieve meaningful control and thereby utilize the full potential of AI.

Professor Peter Werkhoven

Chief Science Officer and member of the Board of Management of TNO and full professor at Utrecht University

Data, Artificial Intelligence and Robotics are part of our present and will be more and more key elements of our future. We must define the scope of their use and protect them as they become part of ourself and of our society. Data but also threats, will increase with the evolution of technologies (5G, pervasive IoT, quantum computing ...): it is important to integrate from the beginning (by design) cybersecurity in the development of innovations in data, AI and robotics. For this reason, the cooperation between ECSO and the new European initiative on data, AI and robotics will be strategic for the development of our economy but also for the protection of our citizens and countries.

Dr. Luigi Rebuffi

Secretary General - ECSO

Executive Summary

Artificial Intelligence (AI), Data and Robotics presents an opportunity and a challenge to Europe, an opportunity to improve the operation of European public and private sectors and a challenge to translate Europe's core AI, Data and Robotics strengths into a global market advantage. The AI, Data and Robotics Partnership is focused on **strengthening research into the market**, developing and **extending Europe's skill base and raising AI, Data and Robotics deployment**. It is likewise focused on the challenges AI, Data and Robotics brings, on new business models and stakeholders, on the need for them to be trustworthy and secure and the need for citizens to see direct benefit from their use.

This is built on the work of BDVA, euRobotics, ELLIS, CLAIRE and EurAI, and it is their joint effort that is presented in this SRIDA (Strategic Research, Innovation and Deployment Agenda). The five organisations are committed to working closely together to see this SRIDA implemented by **building on the AI, Data and Robotics infrastructure and ecosystem** that Europe is creating with Digital Innovation Hubs, Centres of Excellence, Data and AI platforms, etc. All see the benefit of a strong European AI and the advantages this will bring to businesses, citizens, the environment, and the public sector.

The AI, Data and Robotics Partnership will be **open and inclusive** and seeks to create a common view that enable success. It will create impact by focusing on strategic areas that are core to delivering AI, Data and Robotics in Europe. Through **mobilising the ecosystem, the Partnership** will provide strong leadership that is rooted in the widespread deployment of AI, Data and Robotics in sectors and regions across Europe. It will **build on European strengths** to **develop a global AI, Data and Robotics position** that aligns with fundamental European values and delivers technology, products and services that maintain this by seeking to align academic excellence and innovation to the needs of both industry and citizens.

One of the core activities of the Partnership will be to create connectivity across the AI, Data and Robotics ecosystem. Increasing connections will result in improved **academia-industry collaborations** built on a foundation of academic excellence grounded by industrial relevance. Connectivity will **engage member states and regulators** into the ecosystem and researchers and innovators into the market. It will develop new business and new forms of investment. It will create dialogues that address fundamental issues around deployment and citizen trust in AI and will create new partnerships. A key impact will be the **stimulation of industrial investment and private funding** for AI, Data and Robotics in Europe that raises the success of innovators translating research to market. The Partnership is committed to the development of a rich AI, Data and Robotics innovation ecosystem in Europe that is built around a **strong skills pipeline, excellent research** and **effective regulation and standards** coupled to best practice in each sector. The Partnership will provide the focal point for AI, Data and Robotics in Europe.

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The Vision of the Partnership is to boost European competitiveness, societal wellbeing and environmental aspects to lead the world in researching, developing and deploying value-driven trustworthy AI, Data and Robotics based on fundamental European rights, principles and values.

Motivation and Context

The AI, Data and Robotics Partnership is one of the 46 candidate Public Private Partnerships in the upcoming Framework Programme[1]. The impetus for starting the preparatory work on this Partnership came by the European Commission, which adopted in 2018 the Coordinated Plan on Artificial Intelligence[2] announcing the intention to establish a Public Private Partnership on AI, in order to increase available financing for AI in Europe. The document called for private sector partners to commit high levels of investments and referred to the cooperation between BDVA and EuRobotics in this area as a basis to build on for the new Partnership. Following the adoption of this strategic document, BDVA and euRobotics signed a commitment to collaborate (Joint Vision Paper[3]) and started working on the first version of the joint Strategic Research, Innovation and Deployment Agenda (SRIDA)[4], which was published in June 2019. A second version of the SRIDA[5] was released three months later (September 2019) and built on very close collaboration with the AI community and especially CLAIRE, ELLIS and EurAI.

The Strategic Research, Innovation and Deployment Agenda unifies the strategic focus of each of the three disciplines engaged in creating the Partnership on AI, Data and Robotics. More specifically his new third edition of the SRIDA adds viewpoints from each of the three communities to highlight the convergence taking place between them and to provide each community with the opportunity to express their context within the framework of the Partnership. This creates the important focal point needed to identify common challenges and opportunities in research, innovation and deployment for AI, Data and Robotics in Europe.

While each discipline will continue to develop its own strengths and focus on its individual challenges and priorities, the focus of the Partnership is to define and develop common ground between AI, Data and Robotics. In particular, the Partnership is based on the knowledge that the greatest value will be developed in promoting the appropriate convergence of these disciplines. By forging together their distinct characteristics a coherent European vision can be delivered that matches need and delivers value to the market. The Partnership is therefore focused on creating a successful and cohesive eco-system that translates Europe's excellent academic skills into an economic, societal and environmental advantage that embodies European values and norms to achieve the best outcome for Europe.

Each of the five organisations engaged in the Partnership recognises the strength derived from working together to address all aspects of the European vision for AI, Data and Robotics. They recognise the strengths that each community brings to the Partnership and the unique contribution each makes to the whole. This SRIDA sets out the context of this Partnership and identifies the key areas for actions, investments and collaboration, it provides a framework for unifying different approaches to AI, Data and Robotics so that each community can gain advantage from the others through mutual exchange and collaboration.

The Partnership is open and inclusive and seeks to create a common view that enables success in Europe, including the member states. The first and second release of the SRIDA set out how to bring about this vision in practical terms by collaborating with related research, vertical and technology networks. Since the two releases the partners have worked together to submit to the European Commission a detailed application for the AI, Data and Robotics Partnership[6]. Detail has been added to this third edition of the SRIDA to reflect that application, notably in relation to

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1 https://ec.europa.eu/info/horizon-europe-next-research-and-innovation-framework-programme/european-partnerships-horizon-europe_en

2 Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic, and Social Committee and the Committee of the Regions - Coordinated Plan on Artificial Intelligence (COM(2018) 795 final), 7th December, 2018.

3 http://www.bdva.eu/sites/default/files/VISION%20AI-PPP%20euRobotics-BDVA-Final.pdf

4 https://www.bdva.eu/sites/default/files/AI%20PPP%20SRIDA-Consultation%20Version-June%202019%20-%20Online%20version.pdf

5 https://www.bdva.eu/sites/default/files/AI%20PPP%20SRIDA-Second%20Consultation%20Release-September%202019%20-%20Online%20version.pdf

6 https://ec.europa.eu/info/sites/info/files/research_and_innovation/funding/documents/ec_rtd_he-partnerships-artificial-intelligence-data-robotics.pdf

the objectives of the Partnership and its intervention logic and to the enhanced definition of the challenges the Partnership will address. Most notably this third release is significantly enhanced by the three deep dives detailing the Driving Adoption Section.

Scope of the Partnership

The Partnership covers all aspects of AI, Data and Robotics both within and between these disciplines. It is guided by European strategy, by research and by market evidence to ensure that its assessment of opportunity and value creation are aligned with excellence and needs. It will create strategy, rooted in European public funding mechanisms, that can be deployed inside the remit of the Partnership to achieve its objectives. It will also collaborate with other Partnerships and stakeholder organisations where remits fall outside the focus of the Partnership.

The emergence of AI, Data and Robotics in Europe and the development of a trustworthy European approach, coupled to policy objectives, are at the core of the Partnership. Therefore its primary focus falls on regulation, infrastructure, ecosystem-development, industrial support and public acceptance since these are the key drivers for AI, Data and Robotics in Europe. The creation of digital infrastructures, including regulation, the enabling of effective value chains, and the promotion of excellent research and innovation coupled to the retention of talent are all essential for ensuring Europe retains technical knowhow and sovereignty. The Partnership is committed to supporting research, innovation, deployment and commercialisation of AI, Data and Robotics to enable Europe to challenge the global market for AI, Data and Robotics.

Key Impacts

AI, Data and Robotics are transversal and cut across sectors affecting many actors in the value chain. There is widespread acceptance that AI, Data and Robotics will have significant impact on all economic sectors[7] and on the United Nations' Sustainable Development Goals[8]. The proposed actions of the Partnership, set out in this SRIDA, address the series of objectives detailed in the Partnership Application document[9]. These can be summarised in the general objectives of the Partnership, namely:

1. To secure European sovereignty over technologies and knowhow.
2. To establish European leadership with high socio-economic impact.
3. To reinforce a strong and global competitive position for Europe.

The impacts from achieving these objectives occur in at three broad areas:

1. Scientific Impact.
2. Economic and Technological Impact.
3. Societal and Environmental Impact.

Achieving the stated impacts requires more than a strong market and technology position, it needs a skilled workforce and a regulatory and standardisation landscape that can speed up deployment and enable markets to develop; it requires strategy and an understanding of best practice all of which the Partnership will enable. The Partnership provides an opportunity to combine and scale up the impact of public and private investments[10] to create greater value for European business and society through the wide-spread deployment of AI, Data and Robotics.

7 "Notes from the AI frontier: Tackling Europe's gap in digital and artificial intelligence" McKinsey Global Institute February 2019

8 https://www.un.org/sustainabledevelopment/sustainable-development-goals/

9 https://ec.europa.eu/info/sites/info/files/research_and_innovation/funding/documents/ec_rtd_he-partnerships-artificial-intelligence-data-robotics.pdf

10 The BDVA leverage ratio for 2017 is 6.95 (with 1,1 B€ mobilised private investments since the launch of the cPPP at the end of 2014) and for the euRobotics PPP (SPARC) it is 3.6. Full details of the success and impact of the PPPs can be found in their respective Annual Monitoring Reports https://www.eu-robotics.net/sparc/upload/Monitoring-report-2017-final-SPARC-2018_5v0-with-annexes.pdf http://www.bdva.eu/sites/default/files/MR2017_BDV_PPP_Main%20Report_September%202018_1.pdf

EUROPEAN OPPORTUNITIES

The opportunities in Europe are built around both its existing markets and new market opportunities that will be created by deploying AI, Data and Robotics into business and service sectors. There is evidence of investment in AI, Data and Robotics across European sectors but greater action is needed to realise the full value opportunity across all sectors. Strengthening the Innovation Ecosystem by connecting and engaging with AI, Data and Robotics stakeholders will allow the current barriers to adoption to be addressed. The Partnership will work towards maximising the AI, Data and Robotics opportunities in Europe.

Market Opportunities

We already live in the data-driven world. Today, companies are leveraging data to improve customer experiences, open new markets, make employees and processes more productive, and create new sources of competitive advantage – working toward the future of tomorrow. Enterprises are entering a world of multiple innovation, where success is driven by the capability to adopt together emerging technologies such as AI, Data and Robotics with maturing ones such as edge computing and IoT, building on intelligence and learning based on Data. New opportunities will come increasingly from combining digital technology with physical assets, and competition will be increasingly powered by platforms and ecosystems where network effects and innovations feed off themselves. To compete, companies must balance digital and industrial competencies, master them at scale and learn how to collaborate in the new ecosystems. Market demand for innovation will keep growing, but with ever increasing requirements and quality standards.

The sudden stop of economic activities caused by the Covid-19 pandemic has only slowed down investments in digital technologies, which are already picking up at the end of 2020 and are expected to go back to high growing rates from 2021. Based on ongoing surveys, IDC forecasts worldwide spending on AI[11] to jump from 40 B€ in 2019 to 119 B€ in 2025, while spending in Robotics[12] will increase from 86 B€ to 254 B€ in 2025, driven by massive automation investments. The already large Big Data and Analytics (BDA) [13] market will grow from 165 B€ to 294 B€ in 2025.

Alongside the personal and financial loss suffered through the Covid-19 pandemic the wide spread lockdown created an unexpected and unprecedented social upheaval that has demonstrated the usefulness and benefits of remote working and distance learning (as well as some of their shortcomings) which is likely to drive stronger demand for digital services in the near future. There is also a new awareness of the need for collecting and managing data for social welfare and public health.

11 Source: IDC Worldwide Artificial intelligence Spending Guide, August 2020

12 Source: IDC Worldwide Robotics Spending Guide, August 2020

13 Source: IDC Worldwide Big Data and Analytics Spending Guide, August 2020

AI (57.8%)	Robotics (74.9%)	Data[14] (52.1%)
Banking & Insurance	Discrete Manufacturing	Banking & Insurance
Retail & Wholesale	Consumer, and consumer services	Government
Discrete Manufacturing	Process Manufacturing	Discrete Manufacturing
Telecom and Media	Resource Industries	Telecom and Media

Figure 1: Top 4 Sectors for each area in terms of expected financial investments and percentage of total investment

The EU27 share of the AI market is forecast to climb rapidly from only 6 B€ in 2019 (15% of the worldwide market) to 22 B€ in 2025 (18% of the worldwide market), as the European industries adopt intensively AI tools and applications. As shown in the Figure 1 and 2, the three top industries for **AI investments** in 2021 will be Banking and Insurance, Retail and Wholesale and Discrete Manufacturing, all key industries for European economic development. Similarly, IDC forecasts Big **Data** and Analytics (BDA) technologies[15] in the EU27 to increase from 29 B€ to 47 B€ in 2025, a 16% share of worldwide spending. **Robotics investments** in the EU27 are expected to increase at a less fast pace because they start from a higher base, from 12 B€ to 19 B€ in 2025, and they are highly concentrated in a few sectors, with 75% of spending in 2021 driven by Discrete Manufacturing, Consumer devices, Process Manufacturing and Resource industries (Figure 4). On the other hand, spending in Data /BDA technologies is distributed across most industrial sectors (Figure 3), with Finance in the lead with the highest spending actual and forecast.

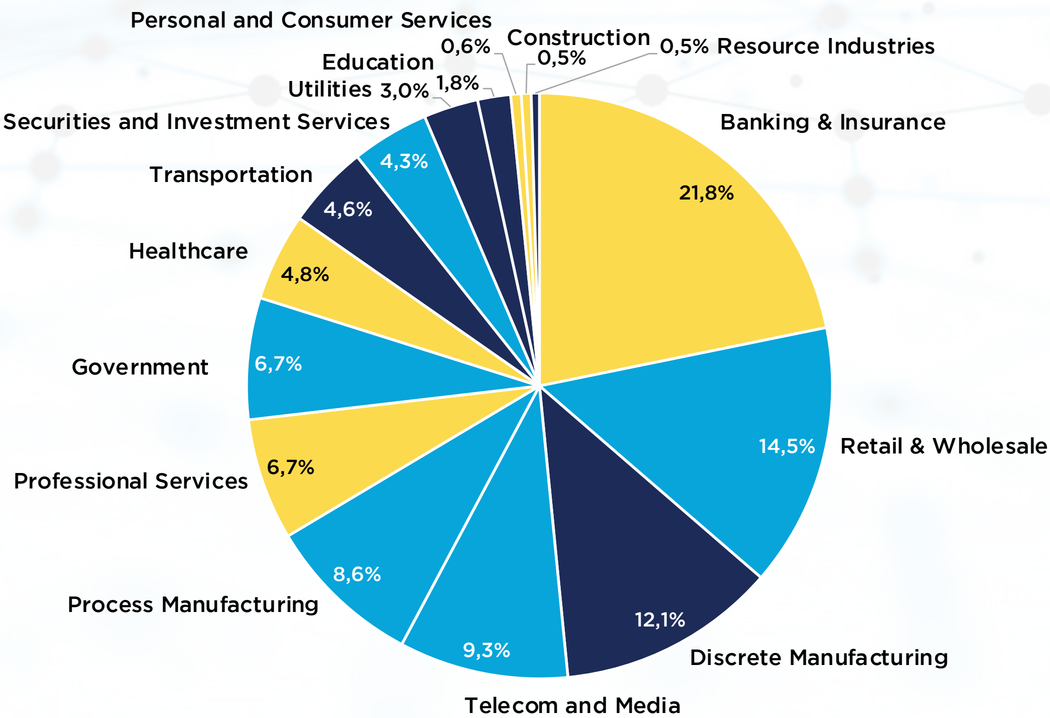

*Figure 2: **AI** Spending by Industry, by percentage of total investment, Western Europe, 2021[16]*

14 IDC summarises Data technologies under the label Big Data and Analytics (BDA)

15 IDC summarises Data technologies under the label Big Data and Analytics (BDA)

16 Source: IDC Worldwide AI Spending Guide, Forecast, August 2020 and IDC Worldwide Robotics Spending Guide, Forecast, August 2020, Western Europe includes: AT, BE, DK, FI, FR, DE, EL, EI, IT, NL, PO, ES, SW, plus CH, NO, UK

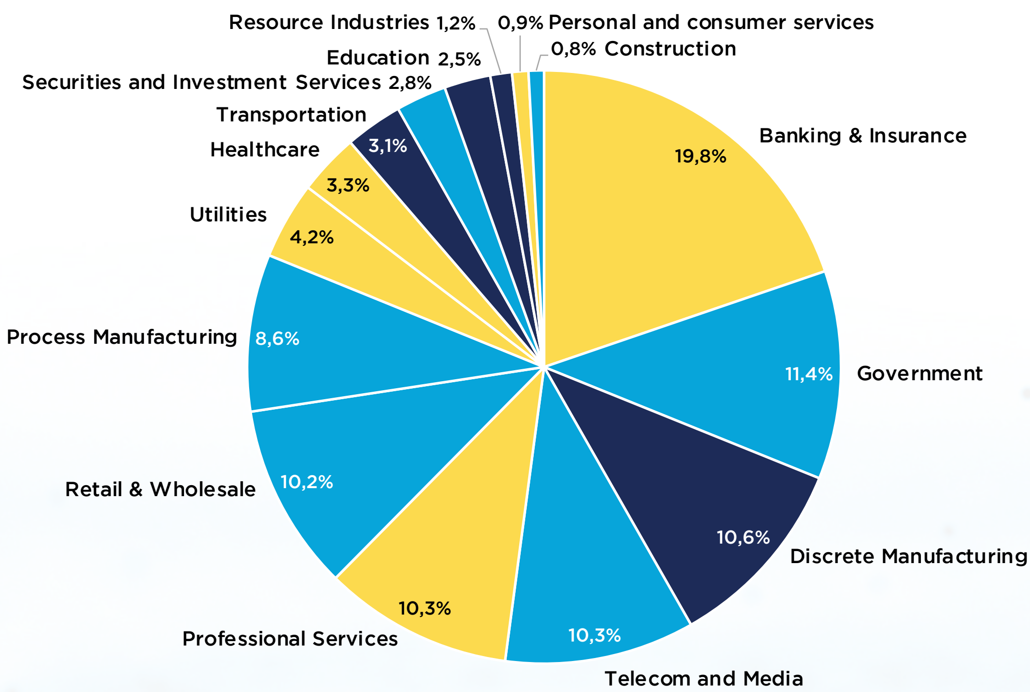

*Figure 3: **Data** Spending by Industry, by percentage of total investment, Western Europe, 2021*[17]

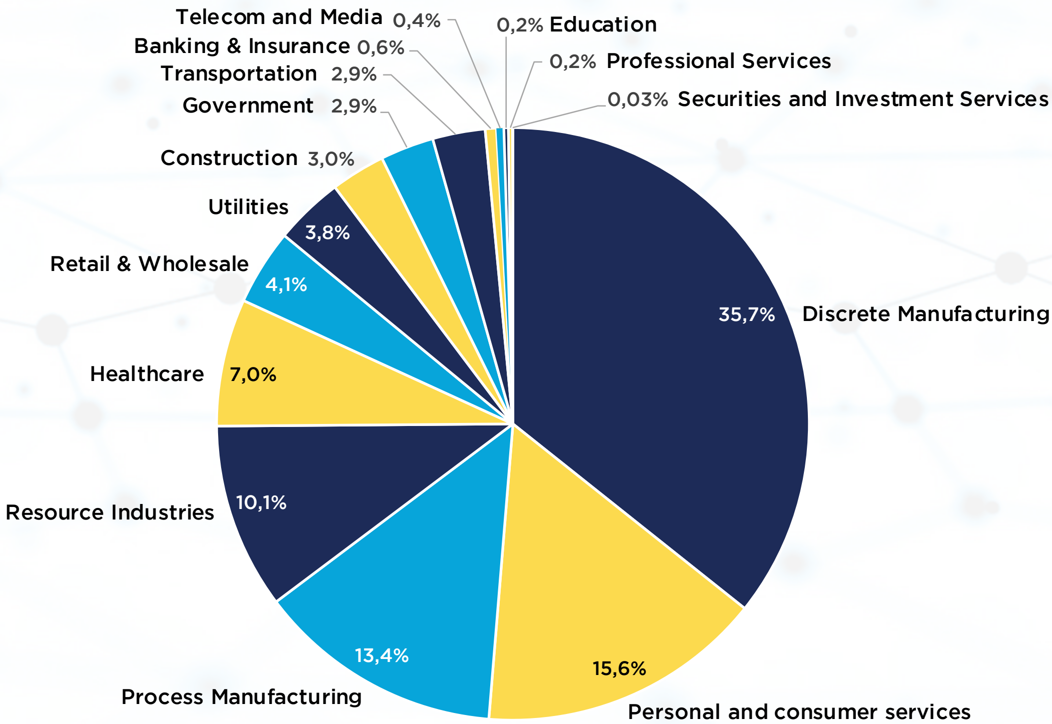

*Figure 4: **Robotics** Spending by Industry, by percentage of total investment, Western Europe, 2021*[18]

The presented numbers indicate the financial investments in AI, Data and Robotics are expected in all markets. In other words, the message from investors is that AI, Data and Robotics are expected to add value across all sectors. This highlights that AI, Data and Robotics opportunities exist across all sectors and domains.

17 IDC Worldwide Big Data and Analytics Spending Guide, Forecast, August 2020 Western Europe includes: AT, BE, DK, FI, FR, DE, EL, EI, IT, NL, PO, ES, SW, plus CH, NO, UK; Note that IDC summarises Data technologies under the label Big Data and Analytics (BDA)

18 Source:IDC Worldwide Robotics Spending Guide, Forecast, August 2020 Western Europe includes: AT, BE, DK, FI, FR, DE, EL, EI, IT, NL, PO, ES, SW, plus CH, NO, UK

Value Opportunities

The deployment of AI, Data and Robotics will impact several main areas:

- By weaving AI, Data and Robotics into the design, manufacturing, production and deployment processes, productivity can be raised.
- By using AI, Data and Robotics to increase autonomy, higher operational flexibility can be achieved.
- By using AI, Data and Robotics to improve usability of products and services (e.g. by allowing greater variations in the human-machine interaction), the user value can be increased and new customer segments addressed, therefore creating new markets.
- By using AI, Data and Robotics for supporting complex decision-making processes in dynamic environments, people can get help in situations of rising complexity (e.g. technical complexity, increasing volatility in markets).
- By developing AI, Data and Robotics for boosting the European ICT companies, for generating new market opportunities and for developing new business models.
- These fundamental impacts are felt at all areas in every market sector.

For instance, AI, Data and Robotics-powered digital technologies will benefit people and society by leading the way in the transformation of the **healthcare sector** including the transition to new care models and, notably, value-based and patient-centric healthcare. AI, Data and Robotics can ensure that care is seamless by delivering solutions across the health continuum. This ranges from helping people to take an active approach to healthy living and prevention; giving clinicians the tools to make first-time-right and personalised diagnosis, and creating new opportunities for intervention, treatment and supporting patient recovery when they return home.

In the area of **telecommunication**, interaction with humans can be complemented with AI, Data and Robotics to scale real-time support to a large number of customers. In addition, the management and optimisation of operations can be improved by predicting and adapting to future demands as well as by ensuring cybersecurity. AI analytics can help to improve performance, efficiency, resilience, and scalability of telecommunication networks.

In **transport**, AI, Data and Robotics will impact both within the existing infrastructure but will also transform it. AI, Data and Robotics is already being used to identify the nature of journeys taken across a city, how flows of traffic change through the day and in different weather conditions. This has an impact on many different stakeholder groups, e.g. city planners learn how to improve the traffic flow and individuals can optimise their travel journey. AI. Data and Robotics also stimulates new businesses based on real-time traffic data that can reshape the city by on-demand transport services replacing personally owned vehicles, by enabling smaller swarms of delivery vehicles and by the removal of carparks from town centres.

There is a similar story that can be told in each area of application. For example, in **manufacturing and production** AI, Data and Robotics delivers productivity gains through more efficient resource, energy and material use, through better design and manufacturing processes and inside products and services, enhancing their operation with more refined contextual knowledge.

In other sectors such as, agriculture, marketing, entertainment and in the service sectors, such as financial services, public services etc., and many others, the impact of AI, Data and Robotics is equally far-reaching.

In addition, all AI, Data and Robotics technologies can be applied to bring value to the missions and clusters in Horizon Europe. For instance, **societal impacts** can be achieved

- in the area of **pandemic emergency response**, *e.g. for fighting Covid-19*[19] Smart systems that enable trusted and transparent contact tracing can directly translate into lower death rates. Trustworthiness is critical to the acceptance of contact and tracing methodologies using smart systems. An overview of how AI, Data and Robotics can help in the battle against the Covid-19 pandemic (including access to different resources) can be found under https://www.eu-robotics.net/eurobotics/newsroom/press/robots-againstcovid-19.html and https://www.eu-robotics.net/eurobotics/newsroom/press/robots-against-covid-19.html?changelang=1
- in the area of **healthcare and cancer**: AI-powered digital technologies will lead the way in transforming the healthcare sector including the transition to new care models and, notably, value-based healthcare as well as new diagnostic methods and treatments, in particular in the area of chronic diseases such as cancer.
- in the area of **smart cities and mobility**: Existing transport infrastructure will be enhanced by intelligent systems aligning personal travel journeys with the flow of traffic, weather conditions, etc.

In addition, AI, Data and Robotics technologies pave the way to materialise **environmental impact**. The Partnership will join forces to maximise its contribution to the *European Green Deal*[20]. A wide range of opportunities exit, for instance

- in the **manufacturing and production** area: AI, Data and Robotics system can help to deliver productivity gains through more efficient resource, energy and material use, through better design and manufacturing processes and inside products and services through improving operational efficiency through more and refined contextual knowledge.
- for the **circular economy**: AI, Data and Robotics technologies can be used to enhance and accelerate the development of new products, components and materials fit for a circular economy, to operate circular business model as well as optimise circular infrastructure[21].
- for optimising **IT systems**: Advances in AI algorithms aiming for optimised HPC computing ensure that AI systems consume less energy. In addition, research in AI will help to reduce carbon footprints required for training deep learning and NLP models.

A recent study from PwC and Microsoft[22] highlights that using AI or **environmental**

19 Further examples of how AI, Data and Robotics can be used to fight Covid-19 can be found under www.bdva.eu/Covid19, https://towardsdatascience.com/artificial-intelligence-against-covid-19-an-early-review-92a8360edaba, Nguyen, T. T. (2020). Artificial intelligence in the battle against coronavirus (COVID-19): a survey and future research directions. Preprint, DOI: 10.13140/RG.2.2.36491.23846 and Pham, Quoc-Viet & C. Nguyen, Dinh & Huynh-The, Thien & Hwang, won-Joo & Pathirana, Pubudu. (2020). Artificial Intelligence (AI) and Big Data for Coronavirus (COVID-19) Pandemic: A Survey on the State-of-the-Arts.

20 https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

21 https://www.mckinsey.com/business-functions/sustainability/our-insights/artificial-intelligence-and-the-circular-economy-ai-as-a-tool-to-accelerate-the-transition

22 Microsoft and PwC: How A can enable a Sustainable Future: https://www.pwc.co.uk/sustainability-climate-change/assets/pdf/how-ai-can-enable-a-sustainable-future.pdf

applications has the potential to boost global GDP by 3.1% to 4.4 % and will help to lower the worldwide greenhouse gas emissions by 4% in 2030. Furthermore, smart systems can provide a valuable contribution to sustainability at large, addressing challenges such as (with an arbitrary choice of concrete examples): climate change monitoring and understanding[23], natural resources[24] and ecosystem[25] management, reduction of the carbon footprint of industrial[26] and human[27] processes, energy efficiency[28] and management, mobility management[29], and infrastructure planning[30]. In these contexts, the scale and complexity of the problems to be solved pose new challenges to current AI techniques that need to be scaled, made global, made more efficient, incorporated into hybrid AI systems and integrated with knowledge coming from human experts. In addition, security issues arising from terrorism-related issues, natural disasters, and epidemics[31], can be also addressed and better managed through smart systems.

In examining the vertical sectors and areas of societal, environmental and economic impact where AI, Data and Robotics can deliver value, it is important to also identify Europe's significant strengths and where there is a strategic priority for Europe. This will help to distinguish European AI, Data and Robotics and identify unique opportunities in the global market.

It is essential that Europe builds on its unique strengths; its strong academic base, its Business to Business expertise and its market leverage on a global scale. AI that is based on core European values will improve trust and acceptance in society that will in turn create a stronger market for AI, Data and Robotics. Europe's comprehensive public sector provides a great opportunity to deploy AI, Data and Robotics in areas that will increase its value to citizens. All of these factors demonstrate that there is a significant opportunity to deploy AI, Data and Robotics in Europe and Europe must now quickly act to maximise the benefit.

Challenges for the Adoption

To generate and capture value in these markets, there are numerous challenges that must be addressed:

Europe's research landscape is fragmented: Europe has a strong AI, Data and Robotics research capability and capacity in academia and research organisations. However, their activities are fragmented between different communities and remain siloed around AI, Data and Robotics, and within the Member States[32]. This makes it more difficult for European organisations to translate research into innovative smart solutions that can impact across regions and globally, as well as feed research with real-world questions. Fragmentation must be addressed; otherwise the results of research, innovation and deployment investments cannot be utilised with maximal efficiency due to redundant and overlapping activities.

23 Better extreme events forecast by the US National Oceanic and Atmospheric Administration
24 Prediction of renewable energy production
25 Wildlife conservation and restauration
26 German Otto distributor optimizes its supply chain by smart prediction of future demand
27 Make the food supply chain sustainable
28 20% energy saving in St Vincent hospital
29 Truck traffic monitoring
30 Monitoring urban growth vs high flood risks
31 For soil moisture prediction
32 European Artificial Intelligence. (AI) leadership, the path for an integrated vision". Policy Department for Economic, Scientific and Quality of Life Policies, Directorate-General for Internal Policies. Laura DELPONTE (CSIL) 2018

Lack of a functioning ecosystem for AI, Data and Robotics: Europe lacks a functioning Ecosystem covering AI, Data and Robotics that can establish the foundation for boosting value created by the innovative development and deployment of these technologies. No single player can achieve this alone; the sharing of assets, technology, skills and knowledge is crucial. In addition, for scaling the deployment of these technologies in real-world applications, a critical mass of engaged stakeholders is needed.

Although Europe has strong ecosystems around Data (BDVA) and Robotics (euRobotics) it needs to develop a single interconnected ecosystem that joins up across the technical areas and across Europe. An ecosystem that overarches European efforts in each of these areas needs to reflect the complexity and diversity of its constituents. It must encompass the three dimensions AI, Data, and Robotics and ensure that knowledge is cross-fertilised. In addition, this requires engagement from all stakeholders in order to be effective and requires alignment between them to ensure efficient collaboration.

High complexity in development and deployment: There are considerable complexity and cost in creating deployable systems in AI, Data and Robotics. In addition, critical requirements such as accuracy, robustness, repeatability and trustworthiness, have to be addressed. This requires dedicated research addressing deployment challenges and requirements across the technologies and around products and services that in turn, rely on complex and smart development and deployment systems.

Lack of Skills and Know-How: Many European organisations lack the skills to manage or deploy smart technical solutions[33] that can be built on these technologies. An increase in talent education is needed. However, a global competition for talent in these areas is underway. Regions with the most vibrant technology landscape are better positioned to attract skilled professionals and retain local talent. Talents are only attracted and retained in the case where conditions are compelling.

Lack of business opportunity understanding: Developing business impact using these smart technologies requires a full understanding of the market, the technology and its impact on business processes and models. Because this requires the integration of knowledge from multiple stakeholders[34], it can result in low levels of uptake driven by uncertainty and a lack of knowledge. In addition, the novelty of these technologies means that emerging business potential may not be obvious from the outset, which in turn slows the return on investment.

Societal Trust in AI, Data and Robotics: There are many misconceptions and much misinformation about AI, Data and Robotics in societal debates, and the technology is not fully accepted by society in all application areas. On the one hand, this will slow uptake, especially where there is unfounded mistrust, but on the other, it may damage markets where its dangers are not fully understood, for example, the limitations of autonomy in road vehicles.

Lack of Infrastructure for AI, Data and Robotics: Both academics and innovators, SME's and start-ups, in particular, need good access to world-class innovation infrastructure including access to data and resources such as HPC and test environments, etc. The lack of accessible and excellent infrastructure will slow market development and limit success.

33 IDC's Western Europe AI/Cognitive Solutions Survey, June 2018

34 Ranging from end user, application provider, user, data supplier, technology creator broker, innovator and entrepreneur, researcher and academic, regulator, standardisation body, investor and venture capitalist as well as citizen.

Policy and Regulation Uncertainty: Policy and regulation of AI, Data and Robotics is still unclear in areas including liability, right to explain, data access and trustworthiness. Many organisations have concerns about compliance. The lack of clarity and the lack of a common European legal framework will slow company growth and the delivery of benefits.

Investment environment: In the international landscape significant private investments[35] in these technologies can be observed. To capture the full range of opportunities offered an appropriately high level of private investment for AI, Data and Robotics in Europe is needed. Engagement of major industries and investors around a common vision and roadmap is essential to reach the full impact of public investment.

European AI, Data and Robotics Innovation Ecosystem

The European AI, Data and Robotics Innovation Ecosystem is complex and diverse. It contains multiple types of stakeholder and, to be effective, there needs to be alignment and collaboration between them. It is the “agora” for the sharing of assets, technology, skills and knowledge. It provides scale to achieve consensus and critical mass around the development of AI, Data and Robotics value through innovation that no single partner alone could achieve. It expresses the collaborative purpose that binds organisations and individuals together in achieving success in deploying AI, Data and Robotics. The Ecosystem is typically composed of:

- **End User:** Person or organisation from different sectors (private and public) that leverage AI, Data and Robotics technologies and services to their advantage.
- **Application Provider:** An organisation that uses AI, Data and/or Robotics technologies for developing a vertical application (e.g. to be offered as AI service).
- **User:** A person who either knowingly or unknowingly uses or is impacted by a system product or service that uses AI, Data and/or Robotics.
- **Data Supplier:** Person or any organisation (public or private) that creates, collects, aggregates, and transforms data from both public and private sources.
- **Technology Creator:** Typically, an organisation (of any size) that creates tools, platforms, services, hardware, and technical knowledge.
- **Broker:** an organisation that connects the supply and demand for AI, Data and/or Robotics assets (such as skills, data, algorithms, infrastructures, etc.) needed for developing applications by providing a channel for exchanging AI, Data and/or Robotics assets.
- **Innovator, Entrepreneur:** Drives the development of innovative AI, Data and Robotics technologies, products, and services.
- **Researcher and Academic:** Researches and investigates new algorithms, hardware, technologies, methodologies, business models; provides skills and training in AI, Data and Robotics and assesses the societal aspects of its impact.
- **Regulator:** Assesses AI, Data and Robotics systems for compliance with regulation, privacy, and legal norms.
- **Standardisation Body:** Defines technology standards (consensus-based, de-

35 €17.9 billion by the U.S., €8.9 billion by China in 2016

facto and formalised) to promote the global adoption of AI, Data and Robotics technologies.

- **Investor, Venture Capitalist:** Provides resources and services to develop the commercial potential of the ecosystem.
- **Citizen:** A person who will or will not develop trust in AI, Data and Robotics technologies.

An effective European AI, Data and Robotics Innovation Ecosystem facilitates the cross-fertilisation and exchange between stakeholders that leads to new AI/Data/Robotics-powered value chains that can improve business and society and deliver benefits to citizens. A productive European AI, Data and Robotics Innovation Ecosystem is an essential component to overcome the key adoption challenges.

DRIVING ADOPTION

Deploying AI, Data and Robotics successfully in Europe requires an integrated landscape for its adoption and the development of AI, Data and Robotics based on Europe's unique characteristics.

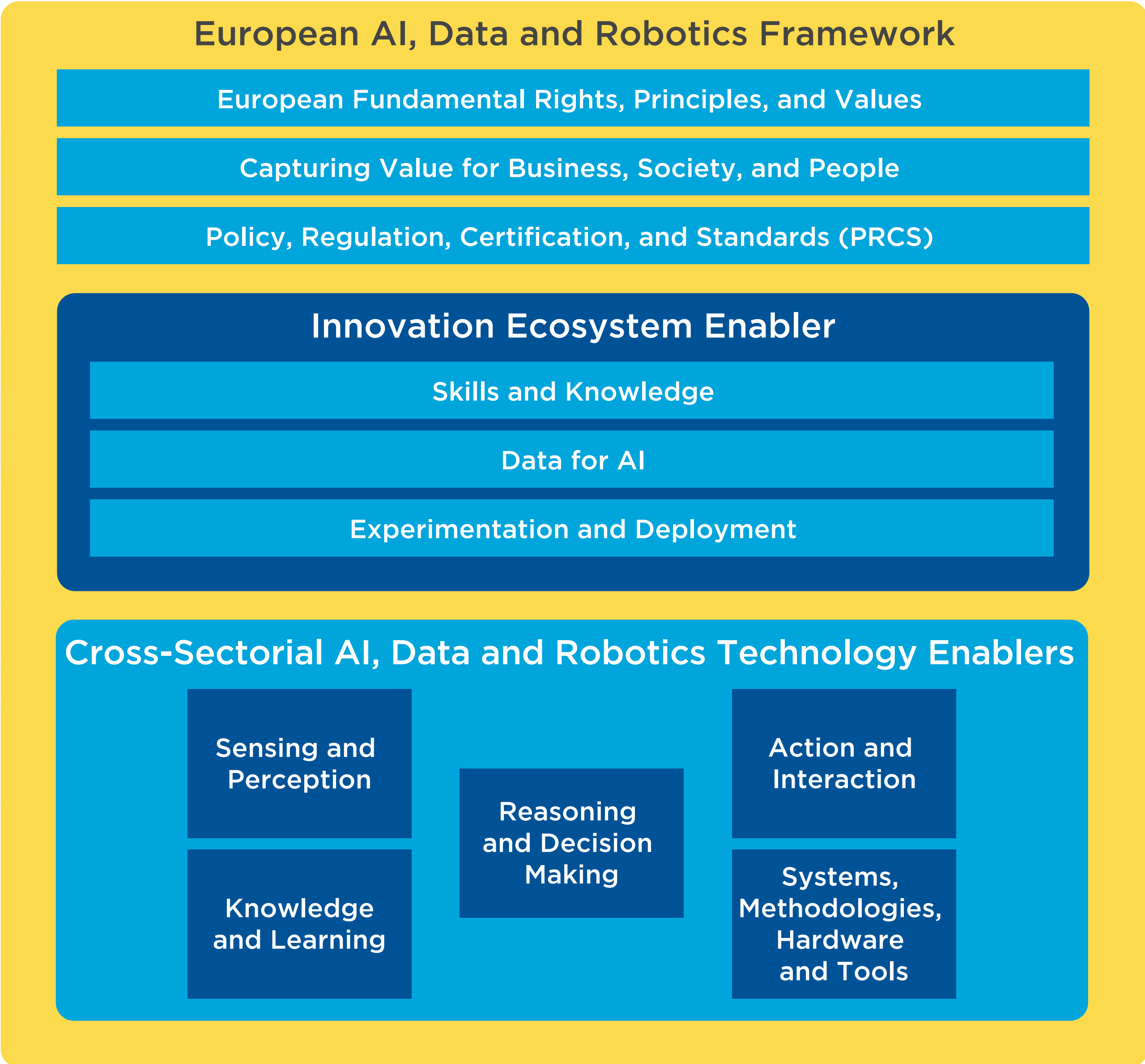

Figure 5: European AI, Data and Robotics Framework and Enablers

Figure 5 sets out the context for the operation of the Partnership. It clusters the primary areas of importance for AI, Data and Robotics research, innovation and deployment into three overarching areas of interest. The *European AI, Data and Robotics Framework* represents the legal and societal fabric that underpins the impact of AI, Data and Robotics on stakeholders and users of the products and services that businesses will provide. The *AI, Data and Robotics Innovation Ecosystem Enablers* represent essential ingredients for effective innovation and deployment to take place. Finally, the *Cross- Sectorial AI, Data and Robotics Technology Enablers* represent the core technical competencies that are essential for the development of AI, Data and Robotics systems.

European AI, Data and Robotics Framework

AI, Data and Robotics technologies work within a broad framework that sets out boundaries and limitations on their use. In specific sectors, such as healthcare, AI, Data and Robotics operates within ethical, legal and societal contexts and within regulatory regimes that can vary across Europe. Products and services based on AI, Data and Robotics must be based on values that are compatible with European rights principles and values. Critical to deploying AI, Data and Robotics is their acceptance by users and citizens, and this acceptance can only come when they can assign trust. This section explores this *European AI, Data and Robotics Framework* within which research, design, development and deployment must work.

European Fundamental Rights, Principles, and Values

Context

On the one hand, the recent advances in AI, Data and Robotics technologies and applications have fundamentally challenged ethical values, human rights and safety in the EU and globally. On the other hand, AI, Data and Robotics offer huge possibilities to raise productivity, address societal challenges and enhance the quality of life for everyone. The European Commission has already taken critical steps towards an European approach for the access, use and exchange of data and the fostering of excellence and trust in AI and Robotics[36].The further development and the implementation of the legal, ethical and societal requirements remain challenging, but they will also provide for business opportunities and enable Europe to strengthen its competitive capacities.

Opportunity and impact of the Partnership

The Partnership has a unique ability to facilitate a multi-stakeholder dialogue that can expose challenges and define approaches to be explored and tested to make fundamental rights, principles and values actionable in practice. In doing so, the Partnership can pave the way towards the operationalising of ethical guidelines and assessment frameworks. The Partnership will also engage with citizens aiming to understand and minimise the apprehension surrounding AI/Data/Robotics-based technologies while seeking to improve their trustworthiness and public adoption. The Partnership will continue to foster research into the 'by-design' approach to privacy and data protection, security and safety and include the scientific questions and business impact of 'ethics-by-design' in the research roadmap. The complexity of the ICT ecosystem and the potential evolutionary nature of AI solutions and of the concept of trustworthiness require further investigation into the development of appropriate trustworthiness frameworks, while integrating continuous improvement.

Concrete actions needed

The Partnership will:

- Facilitate a multi-stakeholder dialogue and consensus building around the core issue of trustworthiness by guiding and shaping a common AI, Data and Robotics agenda, and fostering research and innovation on trustworthy technologies.

36 High-Level Expert Group on Artificial Intelligence, "Ethics Guidelines for Trustworthy AI", 2019; High-Level Expert Group on Artificial Intelligence, "Policy and Investment Recommendations for Trustworthy AI", 2019; European Commission, "The European Data Strategy," 2020; European Commission, "White Paper On Artificial Intelligence – A European approach to excellence and trust", 2020.

- Seek to promote a common understanding among stakeholders of European AI, Data and Robotics fundamental rights and values, so that each sector and community are informed and aware of the potential of AI, Data and Robotics as well as of the risks and limitations of current technologies and will develop guidance in the responsible implementation of AI, Data and Robotics.
- Establish the basis for identifying and expressing a European strategic viewpoint on rights, principles and values by providing clear links to relevant regulation, certification, and standardisation.

Capturing Value for Business, Society, and People

Context

Technical advances in AI, Data and Robotics are enabling real-world applications. These are leading to improved or new value-added chains being developed and integrated. To capture these new forms of value, AI/Data/Robotics-based solutions may require innovative business models that re- define the way stakeholders share investments, risk, know-how, data and consequently value. This alteration of value flow in existing markets can be disruptive and often requires stakeholders to alter their business models and revenue streams. These adjustments require new skills, infrastructure and knowledge and organisations may have to buy in expertise or share data and domain know-how to succeed. This may be particularly difficult if their underlying digitisation skills, a prerequisite for AI, Data and Robotics adoption, are weak.

Even incremental improvements carry risk and may create a reluctance to adopt AI, Data and Robotics. There may be little or no support for change within an organisation or value chain, especially when coupled to a lack of expertise. Successful adoption of AI, Data and Robotics solutions requires a flow of knowledge between the different stakeholders to develop a well-balanced and sustainable value network incorporating all stakeholders' interests, roles and assets that build value.

Opportunity and impact of the Partnership

The role of the Partnership is to mobilise industry and stakeholders in identifying how to build value from AI, Data and Robotics. As a focal point for AI, Data and Robotics in Europe, it will use its strategic influence and position, to foster and propagate a European approach to AI, Data and Robotics that addresses the challenges. It will work with the existing ecosystem to support and enable the deployment of products, processes and services that create value. The goal is to generate stimulating collaborations that foster the discussion around concrete new business opportunities. This is achieved by mapping the technical capabilities of the supply side to the specific end-user needs on the demand side and guiding AI, Data and Robotics innovation stakeholders towards assets, infrastructure and collaborations necessary for success.

Concrete actions needed

To support the adoption of AI, Data and Robotics applications, the Partnership will stimulate discussions to align supply and demand perspectives of the diverse value stakeholders. With the main focus on application areas and sectors that:

- Are crucial for the European economy.
- Relate to critical infrastructure.

- Have a social or environmental impact.
- Can increase European competitiveness in AI, Data and Robotics.

Policy, Regulation, Certification, and Standards (PRCS)

Context

The adoption of AI, Data and Robotics depends on a legal framework of approval built on regulation, partly driven by policy, and an array of certification processes and standards driven by industry. As AI, Data and Robotics are deployed successfully in new market areas, regulation and certification can lag behind thereby creating barriers to adoption.

Similarly, a lack of standards and associated certification and validation methods can hold back deployment and the creation of supply chains and therefore, slow market uptake. In some areas of AI, Data and Robotics, the market will move ahead and wait for regulation to react, but in many application areas existing regulation can present a barrier to adoption and deployment. Most notably in applications where there is close interaction with people, either digitally or physically, or where AI, Data and Robotics technologies are operating in safety or privacy critical environments.

PRCS issues are likely to become a primary area of activity for the Partnership. Regulation is increasingly a primary lever for the adoption of AI/Data/Robotics-systems. Similarly, the development of standards, particularly around data exchange and interoperability will be key to the creation of a European AI, Data and Robotics market place. Establishing how to certify AI, Data and Robotics systems will underpin the development of trust that is essential for acceptance and therefore adoption.

Opportunity and impact of the Partnership

The Partnership will act as a focal point for PRCS issues; its primary role will be as a connector and convenor of groups to address key issues. Its wide connectivity to stakeholders will allow it to bring different parts of the PRCS spectrum together and to identify synergies and cross-cutting opportunities that can attract a critical mass. In this, there will be both long and short term objectives. In the short term, it can connect stakeholders around critical issues and support the development of viewpoints and approaches. In the longer- term, it can support and develop stakeholder communities able to drive standards and processes that will be needed for the mass deployment of AI, Data and Robotics. Critical to this is the coherence of industry around PRCS issues and the embedding of PRCS into research agendas so that emerging technology is already aligned with standards and regulation. In addition, the Partnership also has a role to highlight regulation that creates or has the potential to create barriers to innovation in AI, Data and Robotics, and to foster the adoption and application of a risk-based approach to regulation.

Concrete actions needed

The Partnership will need to carry out the following activities to progress PRCS issues:

- Identify key stakeholders in each area of PRCS and ensure there is good connectivity between them and to the AI, Data and Robotics Ecosystem.
- Work with stakeholders and the emerging AI, Data and Robotics ecosystem infrastructure (Digital Innovation Hubs, pilots, data spaces, etc.) to identify key issues that impact on adoption and deployment in each major sector.

- Promote best practice in deployment regarding PRCS issues and provide signposts to demonstrators and processes that can accelerate uptake.
- Support and collaborate in standardisation initiatives, and the harmonisation of regulation across Europe to create a level AI, Data and Robotics single marketplace[37] and connect with European and Global standards and regulatory bodies.
- Foster the responsible testing of AI, Data and Robotics innovation in regulatory sandbox environments.
- Consolidate recommendations towards policy changes and provide support for related impact assessment processes.
- Drive European thinking and needs towards international standardisation bodies.

Innovation Ecosystem Enablers

The *Innovation Ecosystem Enablers* are essential ingredients for success in the AI, Data and Robotics innovation system. They represent resources that underlie all innovation activity across the sectors and along the innovation chain from research to deployment. Each represents a key area of interest and activity for the Partnership, and each presents unique challenges to the rapid development of European AI, Data and Robotics.

Skills and Knowledge

Context

The uptake of AI, Data and Robotics technologies will affect the skills needed by both industry and wider society. Typically, users of AI/Data/Robotics-based systems will be people without a background in statistics, mathematics, computer science or engineering. In order for AI, Data and Robotics to be acceptable to society, we need to ensure non-expert users have a basic understanding and awareness of these systems and how they operate. This is required in order to avoid the misuse and misunderstanding of AI, Data and Robotics and to ensure that people can accept and trust AI/Data/Robotics-based solutions.

As traditional industry sectors undergo an AI, Data and Robotics transformation, so too must their workforces. There is a clear skills gap when it comes to these technologies. However, while there are shortages of people with specific technical skills or domain knowledge there is also the need to train interdisciplinary experts. AI, Data and Robotic experts need insight into the ethical consequences posed by AI, by machine autonomy and AI augmented processes and services, they need a good understanding of the legal and regulatory landscape, for example, GDPR, and the need to develop and embed trustworthiness, dependability, safety and privacy through the development of appropriate technology, products and services. Crucial for the growth of AI, Data and Robotics in Europe is creating and retaining talent, both in academia and in industry and promoting the flow of talent between them. This can be achieved by investing in research and its infrastructure and in creating favourable investment environments that allow talent to return, grow and stay in Europe.

37 For example the regulations around healthcare data vary considerably from country to country in Europe as do the approaches to the use of image capture in public places

Opportunity and impact of the Partnership

In sectors and domains where AI, Data and Robotics will have strong impact, the Partnership will seek to understand and propagate best practice on collaborative change. The specialisation required by AI, Data and Robotics practitioners will deepen as the sophistication of leading-edge tools and algorithms increases. The skills for general workers will become broader with an increased need for AI, Data and Robotics fluency built on enhanced IT skills and improved numeracy and statistics. The ability to judge bias in both data and algorithms will necessitate transdisciplinary training for knowledge workers. The delivery of AI, Data and Robotics skills to SMEs will also be necessary. Education systems, businesses, governments and social partners will need to adapt to the changing landscape[38].

Concrete actions needed

The Partnership will work through its network to ensure that all stakeholders along the value chain, including citizens and users, have the understanding and skills to work with AI, Data and Robotics enabled systems, in the workplace, in the home and online. The Partnership has a critical role to play in bringing together the key stakeholders; academia, industry, professional trainers, formal and informal education networks and policymakers. These collaborations will need to examine regional strengths and needs in terms of skills across the skill spectrum, both technical and non-technical. It is critical to ensure that the skill pipeline is maintained to ensure the AI transformation of Europe is not held back. Some concrete actions the Partnership will focus on:

- Promote equality and diversity within the current and future workforce to ensure diversity and balance in the educational opportunities that drive the skill pipeline.
- Work towards the alignment of curricula and training programmes for AI, Data and Robotics professionals with industry needs.
- Establish AI, Data and Robotics skills recognition, both technical and non-technical, through certification mechanisms for university courses, professional and vocational training, and informal learning.
- Development of complementary short-courses related to AI, Data and Robotics aimed at decision- makers in industry and public administration, and those wishing to upgrade, enhance or acquire AI, Data and Robotics based skills.
- Support for secondary, or earlier, education and adult learning to cover STEM skills including ethics, social, and the business aspects of AI, Data and Robotics together with the changing nature of work as well as support for vocational training.
- Develop citizen engagement to raise awareness of AI, Data and Robotics and their impact and provide realistic demonstrations of their capabilities and limitations.
- Talent retention, scouting, training, exchange within the EU and between academia and industry including the retention of start-ups and promotion of scale-ups.

Data for AI

Context

For AI and in some aspects of robotics technologies to develop further and meet expectations, large volumes of cross-sectoral, unbiased, high-quality and trustworthy data

38 "AI: THE FUTURE OF WORK? WORK OF THE FUTURE!", Michel Servoz, European Commission (2019)

need to be made available. Data spaces, platforms and marketplaces are enablers, the key to unleashing the potential of such data. There are however important business, organisational and legal constraints that can block this scenario such as the lack of motivation to share data due to ownership concerns; loss of control; lack of trust; the lack of foresight in not understanding the value of data or its sharing potential; the lack of data valuation standards in marketplaces; the legal blocks to the free-flow of data and the uncertainty around data policies. Additionally, significant technical challenges[39] such as interoperability, data verification and provenance support, quality and accuracy, decentralised data sharing and processing architectures, and maturity and uptake of privacy-preserving technologies for big data have a direct impact on the data made available for sharing[40].

Opportunities and impact of the Partnership

Alignment and integration of established data sharing technologies and solutions, and further developments in architectures and governance models aiming to unlock data silos, would enable data analytics across a European data sharing ecosystem[41]. This will enable AI-enhanced digital services to make analysis and predictions on European-wide data, thereby combining Data and Service Economies. New business models will help to exploit the value of those data assets through the implementation of AI and Robotics amongst participating stakeholders including industry, local, national and European authorities and institutions, research entities and even private individuals.

Concrete actions needed

The Partnership will:

- Create the conditions for the development of trusted European data sharing frameworks to enable new data value chain opportunities, building upon existing initiatives and investments (data platforms, i-spaces, big data innovation hubs). Data value chains handling a mix of personal, non-personal, proprietary, closed and open research data need to be supported.
- Promote open datasets and new open benchmarks for AI algorithms, subject to quality validation from both software engineering and functional viewpoints.
- Define specific measures to incorporate data sharing at the core of the data lifecycle for greater access to data, encouraging collaboration between Data Value Chain actors in both directions along the chain and across different sectors.
- Provide supportive measures for European businesses to safely embrace new technologies, practices and policies.
- Facilitate coordination and harmonisation of Member States efforts and realise the potential of European-wide AI-digital services in the face of global competition.
- Guide and influence standards in relation to tools for data sharing, privacy preservation, quality verification, collaboration and interaction.
- Promote standardisation at European level but maintain collaboration with international initiatives for made-in-Europe AI to be adopted worldwide.

39 Details about the technical challenges are covered in the "Knowledge and Learning section"

40 Additional information on challenges at technical, business, organizational, legal compliance, EU-cooperation level can be found in: "Towards a European Data Sharing Space: Enabling data exchanga and unlocking AI potential". http://www.bdva.eu/sites/default/files/BDVA%20DataSharingSpace%20PositionPaper_April2019_V1.pdf

41 that includes research centres`, industry, government and multi-national bodies, by leveraging existing pan-European initiatives, platforms and networks

Experimentation and Deployment

Context

Experimentation is a critical for AI/Data/Robotics-based innovation because of the need to deploy in complex physical and digital environments. This includes safe environments for experimentation to explore the data value as well as to test the operation of autonomous actors. AI-driven innovations rely on the interplay of different assets, such as data, robotics, algorithms and infrastructure. For that reason, *cooperation* with other partners is central to gaining access to required assets. This includes access to the AI, Data and Robotics ecosystem covering AI platform providers, data scientists, data owners, providers, consumers, specialised consultancy, etc.

Opportunity and impact of the Partnership

The partnership will stimulate the development of experimentation environments and sandboxes where companies and researchers, including SMEs, can test their AI, Data and Robotics based services and products efficiently and sufficiently prior to market deployment. Access to these testing environments is a key part of the offering from AI Digital Innovation Hubs, including the provision of infrastructure, technical support, skills, data, etc. including incubation and acceleration services. These enable companies to rapidly develop new businesses based on AI, Data and Robotics technologies, applications and models.

Concrete actions needed

The Partnership will:

- Stimulate cooperation between all stakeholders in the AI, Data and Robotics value chain around experimentation and deployment.
- Enable access to infrastructure and tools together with data sets covering the whole value chain as a basis for doing experiments to support development and deployment.
- Support the creation and linking of DIHs, centres of excellence and all other EC initiatives on the AI infrastructure.
- Support AI-based incubators as well as testbed developments as well as promote initiatives that enable SME access to infrastructure and tools at low cost.
- Foster set-ups that bring together industrial user with research excellence, domain experts with data scientists, aiming to fill the gaps between domain/business and technical expertise.
- Establish AI, Data and Robotics large scale demonstrators aligned to European industry needs to validate performance, with the expectation of support from regional and national infrastructures.

Cross-Sectorial AI, Data and Robotics Technology Enablers

The following sections detail each of the *technology enablers* and illustrate their inter-dependence in building successful AI, Data and Robotics products and services. Each technology enabler needs to work in unison to achieve optimal function and performance. They represent the fundamental building blocks needed to create AI, Data and Robotics systems of all types.

The *Sensing and Perception and Knowledge and Learning* technology enablers create the data and knowledge on which decisions are made. These are used by the *Reasoning and Decision Making* technologies to deliver; edge and cloud-based decision making, planning, search and optimisation in systems, and the multi-layered decision making necessary for AI, Data and Robotic systems operating in complex environments.

Action and Interaction covers the challenges of human interaction, machine to machine inter-operation and machine interaction with the human environment. These multiple forms of action and interaction create complex challenges that range from the optimisation of performance to physical safety and social interaction with humans in unstructured and multi-faceted environments.

Systems, Hardware, Methods and Tools provide the technologies that enable the construction and configuring of systems, whether they are built purely on data or on autonomous robots. These tools, methods and processes integrate AI, Data and Robotics technologies into systems and are responsible for ensuring that core system properties and characteristics such as safety, robustness, dependability and trustworthiness can be integrated into the design cycle, tested, validated and ultimately certified for use.

Each technical area overlaps with the other, there are no clear boundaries, indeed exciting advances are most often made in the intersections between these five areas and the system level synergies that emerge from the interconnections between them.

One of the core characteristics that AI enabled systems need to display is trustworthiness. Building systems that can be trusted is critical to their acceptance and therefore to successful deployment. Although only some critical AI applications need high levels of trustworthiness all applications need to be trustable. Trustworthiness is a property of the whole system created by the interaction between technology building blocks. It must be designed into the system as no single technology embodies it,. Trustworthiness is built on multiple underlying system characteristics; reliability, dependability, safety, etc. and on the behaviour displayed by the system during its operation.

Sensing and Perception

Overview

Sensing and perception technologies create information needed for successful decision making, learning and interaction. They encompass methods to access, assess, convert and aggregate signals that represent real-world parameters into processable and communicable data assets that embody perception. They encompass sensing and processing methods, and the architecture of sensing and perception systems. They create filtered and managed data streams and fill data stores and provide meta-data contexts. They address the parameters of acquisition, speed, resolution, range and quality and the technologies used to combine and fuse data to deliver an accurate picture of the world, be that from a website, a moving vehicle, a factory process or the reactions of people watching a TV advert.

Within this technology enabler, the digital and physical become inseparable. This is the crossover point between the physical world and its digital representation. Digital representations of, physical motion, visual images, text, sounds, haptics, chemistry and the human body are all fundamental to building a representation of the world around us. Sensing is grounded in the real world by frames of reference, while perception builds information into data assets that can be communicated, shared, processed and utilised by AI, Data and Robotic systems; These technologies are built around different types of data:

- Gathered from sensors[42], often in real time.
- Acquired from measurement systems.
- Extracted from accumulated time series.
- Extracted from unstructured data such as text, video, image and sound input.
- Referenced from data stores.

Sensing and Perception lies at the core of AI, Data and Robotics in all key sectors; healthcare, agri-food, manufacturing, logistics etc. and for data derived from static and dynamic sources such as satellite weather data, seismic, air pollution or ocean sensing data.

In addition to the capture of sense data, perception and interpretation technologies are also important. In particular, Natural Language Processing has particular resonance within Europe's multi-lingual landscape and offers the potential to harmonise human interaction.

Dependencies

While the development of novel sensors mostly comes from outside the AI, Data and Robotics community, mainly from the materials and semi-conductor industries, the definition of data flows, interfaces and standardised meta-information, and the specifications for processing methods and operational parameters such as range, sensitivity etc. are often unique to the needs of AI, Data and Robotics technologies. These applications also place constraints on data capture and processing, for example, on energy consumption or data accessibility where privacy is important.

	Knowledge and Learning	Reasoning and Decision Making	Action and Interaction	Systems, Hardware, Methodologies and Tools
Sensing and Perception	Provides these with processed sensed data and measurements	Provides these with context information	Provides data streams for interaction and closed control loops	Depends on architecture and data flow standards for perception processing and data asset exchange

Sensing and perception technologies are used across all sectors and draw on core technologies from a wide range of industry supply chains related to semi-conductors, materials, embedded systems, signal processing and metrology. AI, Data and Robotics applications are dependent on timely, high-quality data that is rich in information and reliable.

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Challenges

The following high-level application driven challenges exist in this technology enabler:

- The development of faster more accurate methods of perception that cover all types of data modalities (text, video, image, sound, sensor, etc.) and that can

42 A sensor is a physical device that detects or measures a physical property. Examples are cameras for images and video, microphone for sound, keyboard for text, a shaft encoder for rotation, or an accelerometer for motion.

operate across a wide range of environmental conditions; different weather, diverse everyday objects, different human emotions and ages, different behaviours and diverse human interactions.

- The development of active perception technologies that use cognition to guide the perceptual process; for example, prior knowledge and expectations can be used to focus sensing, for example, image interpretation may support text understanding, video may contextualise sound processing.
- The modularisation and standardisation of sensor interfaces, meta-information models and data flows; for example interfaces that can adapt to the balance between processing within the sensor (e.g. edge) and processing centrally (e.g. cloud); or handle both local and distributed data capture; or adapt processing methods to changing operating conditions or dynamics.
- The development of novel sensing and sensor systems for AI, Data and Robotics applications; for example in challenging environments; low and high temperature, pressure or in corrosive and explosive atmospheres, bio and chemical sensing, bio-compatible sensors and low cost, low energy, high accuracy sensors.
- The development of methods to validate and certify sensor systems for safety, privacy, trustworthiness, etc.; for example, safety certifiable sensors for human-robot interaction, body pose detection or in-vivo physical interfaces.
- The development of advanced sensors able to adapt and self-calibrate, zero- energy sensor and sensors that can be embedded in retail packaging, bridges or people.

Outcomes / Expected Impact

Better and smarter sensing and perception, will result in more accurate and timely decision making, improved perception of operating conditions and environments.

Wearable and embedded sensing will improve human interaction and the interaction of AI, Data and Robotics systems with objects and infrastructure. Distributed sensing linked into networks, for example, in connected autonomous vehicles, will create a broader spectrum of information from which AI can make better decisions. Improved accuracy and speed will improve control systems and automation and allow greater levels of autonomy.

Short Term	***Medium Term***	***Longer Term***
Standardised and modular sensors will create cross- sector supply chains and reduce costs Sensors and sensor systems will become cheaper to manufacture with better data quality; designs will become more compact and integrated Improved text, image, video, sound and sensor processing	The ability to modularise and fuse information from distributed and multi-modal sensor systems will become more standardised Greater integration of sensing and processing in modular packages Secure and intrinsically safe sensing systems Advances expected in chemical and bio-based sensing triggered by medical applications Improved accuracy through advances in active perception technologies	New materials and processing techniques will yield new forms of sensing and data acquisition Low or zero energy systems based on ambient energy Self-configuring and adaptive sensors IoT supported by ubiquitous networks of AI-based sensors Newly emerging sensing principles

Knowledge and Learning

Overview

Knowledge and learning technologies, including data processing technologies, cover the transformation, cleaning, storage, sharing, modelling, simulation, synthesising and extracting of insights of all types of data both that gathered through sensing and perception as well as data acquired by other means, for example financial transaction data, or marketing data. These technologies encompass both data-driven and knowledge-based models and the management of knowledge and learning methodologies and processes. These technologies enable

- closing the loop from data-driven, automated analytics and knowledge-based decision support to fully automated enactment and actuation of decision, a significantly *higher level of automation and reliability* of processes becomes possible.
- *the assessment and assurance of safe and reliable functioning of autonomous systems* in the real world in a wide range of applications including autonomous cars, drones, delivery of goods and environmental monitoring.
- to have a sustainable models of complex systems (*digital twins*) for example along the complete lifecycle (product and production) of a product or system, or of complex environments such as healthcare that create value from underlying data and characterisations.

This enabling technology can be divided into different areas:

- Improving the data assets by addressing data pre-processing challenges for learning techniques to derive insights, patterns, events, data anomalies detection, sentiment and emotion analytics, etc. from heterogeneous data sources, and the provision of advanced learning techniques.
- ***Generating*** domain related **knowledge representations** establishing the basis for *seamless incorporation of background knowledge into AI, Data and Robotics applications*. This includes approaches that combine data-driven learning with knowledge-based approaches (hybrid AI), simulation technologies and digital twins, methods that enable the data processing at the location where the data is produced (edge based AI) and methods for knowledge representation and learning.

Dependencies

The development of data, Knowledge and Learning technologies establishes the basis to incorporate domain knowledge, the physical environment, underlying processes and other interrelations into the system function. It is an important processing step enabling the transforming of complex data assets into high quality input for trusted decision making.

	Sensing and Perception	Reasoning and Decision Making	Action and Interaction	Systems, Hardware, Methodologies and Tools
Knowledge and Learning	Enrichment of raw data to high quality data	Provides pre- processed data in high quality Integrate data-driven and knowledge-based decision and optimisation models	Provides formal representation of physical world and context information guiding the interaction	Depends on architecture and data flow standards

Challenges

The following high-level application driven challenges exist in this technology enabler:

- The *scaling and federation of AI systems* ensuring that simple AI-models can seamlessly be composed and combined into large scale federated systems. This includes scenarios based on distributed data storage locations, for *data-in-motion* and *data-in-rest* while satisfying the privacy, robustness and performance requirements from the user side.
- The development of *data augmentation* methods for transforming data assets into high-quality and augmented training data. This includes the automated generating of data labels, the generation of synthetic data, automatic methods for data verification as well as methods to extract insights from small data.
- Methods for *knowledge modelling* and representation that enable the seamless integration of data and connection with the physical world. To support reuse of integrated and continuous knowledge its representation in standardises format.
- Advanced *learning methods* to ensure scalability, reusability and explainability of analytical outcome. This includes approaches for transfer learning, better online (e.g., continual lifelong) learning, explainable learning, meta-learning and knowledge representation learning.
- Methods that *integrate data-driven* and knowledge-based approaches to ensure that AI system use all the available sources of information, and that models trained by data are legible for humans and are compliant to given specifications.
- The development of methods for handling *security and privacy concerns*. This includes GDPR-compliancy in processing and sharing of data sources, ensuring data privacy and data security standards along the data lifecycle which also applies to distributed data and real-time data.

Outcomes / Expected Impact

By incorporating learning, knowledge and data assets, it becomes possible to optimise the creation of more complex AI, Data and Robotics applications leading to higher quality outcomes with lower construction effort.

Short Term	***Medium Term***	***Longer Term***
Provide automated data quality and filtering as input to AI components in order to avoid bias, imbalanced data Integrate domain knowledge into the data-driven data analytics process Ensure reliable data and transparency of input data Approaches for the automated generating of reliable training data	Means for the efficient semi-automated generation of domain knowledge models Scalable and seamless combination of analytical models Development of compact and secure and privacy-preserving algorithm for distributed data Extraction of valuable insights from small data Efficient means for transfer learning and explainable learning	Enable transparency by learning understandable models (open the black box) Intrinsically trustworthy knowledge modelling Hybrid knowledge representation Effective applications of model-based AI Support for human interrogation of AI decision making Development of intrinsically secure and privacy-preserving algorithm Reduction of the data demand for learning

Reasoning and Decision Making

Overview

Reasoning and Decision making are at the heart of Artificial Intelligence. This technology area also addresses optimisation, search, planning, diagnosis and relies on methods to ensure robustness and trustworthiness. Four scenarios can be considered that illustrate the different ways these critical technologies are utilised:

- *Human Decision Making.* When people interpret the output of AI-based systems to make decisions and take actions. For example in a manufacturing plant, the supervisor analyses the output of several predictive models in order to immediately stop the plant to repair a single machine or wait until the next scheduled maintenance stop. Here the consequences of the decision are assessed by a person or a team.
- *Machine Decision Making.* When actions are carried out autonomously by an AI-based system. For example, self-driving cars or drones. The consequences are assessed by the AI-based system and where there is often a hard timing constraint.
- *Mixed Decision Making and Decision Support.* When decisions taken balance between humans and machines. The consequences are evaluated taking into account the criteria of people (a person or a team) and the machine's criteria.
- *Sliding or Variable Decision Making.* When the balance between human and machine decision making varies during operation depending on machine based confidence levels or human interaction.
- *Collective and distributed decision making* where solutions depend on the interests and power of different parties involved and an optimal solution is an accepted solution rather than some kind of "objective" optimum.

In all these scenarios different methods for decision making can be utilised and constraints and uncertainty taken into account. The quality of decisions is heavily dependent on the quality of input data and knowledge including symbolic and non-symbolic data.

Dependencies

Decision-making is at the centre of many AI, Data and Robotics-based systems. As such, it has many dependencies on other technologies that supply, process and store information.

	Sensing and Perception	Knowledge and Learning	Action and Interaction	Systems, Hardware, Methodologies and Tools
Reasoning and Decision-Making	Enrichment of raw data to high-quality data	Integrated high-quality, unbiased data for decision making (including domain knowledge)	Provides a formal representation of the physical world and context information guiding the interaction	Depends on architecture and data flow standards

Challenges

All three scenarios face combinations of the following challenges:

- *Timeliness:* ranging from decisions that must be taken immediately, in a matter of milliseconds, because the next steps/actions depend on every single decision (e.g. self-driving cars), to decisions that can be postponed with minimal risks or costs (e.g. predictive maintenance in production plants).
- *Robustness* ensuring that decision making maintains its level of performance under any circumstance.

- *Trustworthiness* increasing users' confidence in an AI and Robotics System by making it dependable and reliable. To increase trust in AI and Robotics systems, different aspects, such as transparency, explainability or controllability might be needed to be addressed.

The following high-level challenges exist in this technology enabler:

- *Interpretation of context:* Guiding machine or human to better understand the proposed recommendation / decision. This includes methods for providing explanations as well as methods ensuring interpretability of models.
- *Dealing with uncertainty:* Decisions must be taken in the face of uncertainty in the models, in perceptual data, and the effects of the system's actions. Resilient AI and Robotics systems must be able to cope with incomplete and contradictory information by combining quantitative and qualitative methods.
- *Transparent anticipation:* Decision making often involves the use of predictive models to forecast possible futures and take anticipatory actions. To ensure trustworthy decisions, it must be possible for both the designers and the users to inspect, understand, validate and possibly challenge these models, as well as the criteria used to make a choice based on their predictions.
- *Reliability:* The challenge is to build decision making systems that prioritise the same option(s) for similar input consistently.
- *Human-centric* planning and decision making requires the incorporation of background knowledge and mental models of human users when deciding the best sequence of action as well as information of related processes, activities or tasks.
- *Augmented decision making* that complements human cognitive capabilities in a supportive way that humans are free to focus on less repetitive and more advanced tasks.

Outcomes / Expected Impact

By incorporating quality-controlled data within transparent decision-making processed AI-based decision making can be reliably incorporated into more sophisticated applications.

Short Term	*Medium Term*	*Longer Term*
Techniques for hybrid decision making Improve the human understandability of AI-produced decision Provide simple explanations detailing the rationale of a decision Ensure robust and reliable decision-making Increased transparency by estimating model uncertainty	Provide trustworthy and robust hybrid AI-based decision making Enable user dialogue to inform the user about the decision's rationale Efficient means for handling uncertainty in complex setting Reliable real-time decision making in dynamic and multi-actor environments Dependable decision making in safety and privacy critical environment Constraint-based planning and decision making in complex natural environments Planning and decision making under uncertainty	Explainable decision-making incorporating context information Intrinsically trustworthy decision making Human interrogation for decision making Adaptive decision-making by incorporation of environmental changes Human-centric and compatible decision-making by incorporation of social interaction and mental models

Action and Interaction

Overview

The technologies in this enabler embody every aspect of digital and physical AI working together. Interactions occur between machines and objects, between machines, between people and machines and between environments and machines. Interactions are shaped by real-time data acquisition, by stored information, by long term knowledge accumulation and multiple modalities and languages. At a more abstract level, humans interact, sometimes knowingly and sometimes unknowingly, with embedded AI, for example in financial or telecommunication systems. To achieve the seamless operation systems reliant on AI technologies need to interact smoothly and harmoniously to achieve appropriate physical actions and interactions that respect their social, physical and environmental context.

Dependencies

Action and Interaction technologies depend on high quality reasoning and decision making and on immediate data and embedded knowledge. In addition, there is often a need for regulatory compliance, especially when operating in close proximity to people. Interaction with people, particularly social interaction, is dependent on understanding social norms for interaction, for example, when handing a screwdriver to someone on a ladder. Interaction also needs to adhere to privacy and ethical norms, both in digital and physical spaces.

These technologies have numerous technical dependencies, for example, on natural language processing, on-scene interpretation, on human interface technologies. They also depend on contextual data, models of interaction and semantic data about physical objects, for example, how best to grasp each of the objects in a warehouse.

	Sensing and Perception	Knowledge and Learning	Reasoning and Decision Making	Systems, Hardware, Methodologies and Tools
Action and Interaction	Depends on sensing of motion and mechanical properties Relies on perception for interaction Uses recognition of actions and sequences of interactions in people	Gets semantic knowledge around objects and human actions Gets data on objects and places	Depends on real-time context-aware decision making Trusted decision making	Depends on fast reactive architectures for control Relies on edge-based AI Requires assurance of safe operation and data privacy

Challenges

There are a set of core challenges in the interaction technologies that relate to the processing of environmental cues to guide the decisional autonomy that drives the sequences of individual actions that form an interaction. This can involve multiple sources of data and the interpretation of perceptions within the context of an interaction sequence. For example, interpreting the meaning of the spoken word in the context of an on-going interaction. Or understanding the consequence of detecting liquid in a container and the effect that might have on developing a grasping and movement plan.

Within these generic interaction challenges, the following more detailed challenges also exist:

- The development of techniques and methods to achieve seamless and n*atural interaction in unstructured contexts*, including multi-modal interaction and the development of generic interaction models.
- Improved *natural language understanding, interaction and dialogue* covering all European languages and age ranges
- Development of *verbal and non-verbal interaction* models for people and machines, including gesture and emotion based interaction.
- The development of interaction technologies using *Virtual Reality (VR) and Augmented Reality (AR)* and their relation to human interaction both digital and physical.
- The *co-development of technology and regulation* to assure safe interaction in safety-critical and unstructured environments. This includes the development of actuators, mechanisms and control strategies for safe operation.
- The development of *confidence measures* for interaction and the interpretation of actions leading to explanations of interaction decisions and improved decision making.
- The development of robust, interactive machine learning and decision support systems that interact with domain experts to obtain more accurate and realistic models.

Outcomes / Expected Impact

The expectation is that the further development of interaction technologies will lead to faster, more intuitive interactions that can take place over more extended time frames and in multiple areas of competence. That social interaction can be carried out in a broader range of circumstances, linguistic and cultural context and that interactions can take place between multiple agents.

Short Term	***Medium Term***	***Longer Term***
Improved application specific multi-modal multilingual interaction Improved interaction based on perception of non-verbal and emotion cues Extended use of VR and AR in interactions Agreed safety criteria for co-working in production Increased augmentation of human task Affordable implementation of digital companion	Longer continuous meaningful multilingual interactions over periods of 10 minutes or more Generic standards for multi-modal interaction Safe, human compatible, physical and social interaction and collaboration in a limited range of tasks Improved dexterous manipulation of unknown objects Increased automation supporting human work	Continued interaction over extended time periods of hours Ability to carry out complex dexterous tasks autonomously Complex collaborative interaction between multiple agents Complex social interaction in multi-actor environments Human environment reconfigured around interaction Safe interaction in dynamic and uncertain environments

Systems, Methodologies, Hardware and Tools

Overview

AI, Data and Robotics systems are complex. They integrate diverse technologies, from software and hardware to physical structures. They can be distributed or local, large or small scale, they can operate unattended or have complex human interfaces. Designing, developing and deploying these systems has its own technology methodologies and landscape; support tools, system architectures, validation processes and modularity standards etc. These enabling technologies ensure that the designer, integrator and deployer can efficiently deliver AI, Data and Robotics systems that perform to specification. These enabling technologies cover:

- Software engineering methodologies (for AI, Data and Robotics).
- Systems engineering and integration science, including Systems of Systems development.
- Hardware systems architecture and design; mechanical, electrical, electronic, computational, sensing, actuation, control etc.
- Tools and processes for; design, deployment, testing, validation and certification etc.
- Modularity and Interoperability (Standards).

AI technologies, and in particular autonomy, brings specific challenges to the construction of both digital and physical systems where they interact closely with people, either physically or in terms of personal data, especially vulnerable people, and in hazardous or critical environments. Here there is a strong expectation that the principle of "*... by design*[43]" can be extended to include ethics, privacy, trustworthiness etc. thereby delivering compliance and performance guarantees.

Dependencies

These enabling technologies depend on standards and processes that have a global dimension. They provide the basis for quality assurance including trustworthiness, privacy etc. In some cases these may be set by legislation and regulation, particularly where AI, Data and Robotics systems interact with and affect people. In some critical environments the regulatory processes may determine the system architecture, and as regulation changes, architecture will be adapted to exploit or enact it.

	Sensing and Perception	Knowledge and Learning	Reasoning and Decision Making	Action and Interaction
Systems, Hardware, Methodologies and Tools	Sets constraints on digital and physical architectures	Provides knowledge used in model-driven design	Provides techniques for automated design processes	Sets constraints on digital and physical architectures

Challenges

At the core of *all challenges* in this enabling area is the need to develop, and guarantee that,

43 The concept of "... by design" covers the idea that, for example, safety, quality etc. can be built into a design through the design process.

systems meet a diverse range of system and behavioural design parameters. Parameters such as safety, trustworthiness, dependability; as well as technical parameters such as performance, latency, energy consumption, data use, processor power, communication bandwidth etc.

Achieving these diverse system level requirements requires tools, processes, architectures and standards that can be shown to build confidence that systems are fit for purpose. Efficient design and development processes lead directly to faster time to market, but the goal of right-first-time development remains a significant challenge for complex AI, Data and Robotics systems.

This fundamental challenge flows through all parts of the design, development and deployment cycle. The following high-level application driven challenges exist in this technology enabler:

- To develop tools that enable the design, development and deployment of AI, Data and Robotics systems that achieve their requirements at a behavioural level and a technical level through the design and development process.
- To develop system integration processes and methodologies that are cross domain and allow efficient system design that can deliver against Quality of Service criteria. In particular, these should integrate certification and validation criteria.
- To develop methodologies and processes that ensure that design and development consider the whole life cycle of a product or service, especially where the product learns to alter its behaviour over time and when it operates autonomously in unknowable environments. Existing exhaustive testing regimes are costly and act as a barrier to deployment; design-based autonomy assurance is a critical challenge.
- To develop system architectures and modular standards that encompass all aspects of data and physical systems. Critical to this is the co-development of data and physical standards of modularity, and the development of data standards for exchange and data asset generation that cover real-time, contextual, physical digital contexts and their associated meta-data. Data architectures will have to appropriately balance between cloud functionalities and computing at the edge.
- To develop methods and metrics to evaluate the performance of AI, Data and Robotics systems, including the development of suitable benchmarks for complex, integrated and evolving systems.

Outcomes / Expected Impact

The primary outcome from improving these enabling technologies is the speeding up the development and deployment processes. Firstly, by improving the productivity of designers and system integrators and secondly by speeding up the testing and validation of designs. Discovering how to build "*... by design*" into tools and processes will enable performance and behaviour guarantees to be delivered.

Short Term	Medium Term	Longer Term
Data standards for exchange and meta data standards Platforms for data and algorithm sharing Testing and validation processes standardised Wide acceptance of definitions for dependability and trustworthiness Data quality standards Usability and human-machine interaction quality standards	Tools and processes that can more rapidly create AI, Data and Robotics systems with guaranteed performance Standardised trustworthiness AI architectures standardised and built into design tools System-level component modularity creating cross- sector supply chains Standardised knowledge models across domains	Stable design patterns across sectors Automated testing and soft validation of systems, including physical systems able to guarantee regulatory compliance Safety autonomous learning used in critical applications Assurance of autonomous systems in safety and privacy critical environments

AI DEEP DIVE

Overview of Artificial Intelligence

Artificial Intelligence

At its core, as a technical field, AI focuses on developing techniques to perform tasks that we normally associate with the application of intelligence. That is the reason why mimicking tasks such as learning, reasoning, planning and interacting with other intelligent agents are of interest – as well as addressing challenging tasks like understanding human language, intentions and actions, along with solving hard problems such as scheduling, theorem proving and constraint optimisation. In basic science, this leads to a quest for an understanding of the mechanisms underlying thought and intelligent behavior and their embodiment in machines. In applied science, this leads to a quest for new methods for solving difficult problems. In business this leads to a quest for combining these advancements with increasingly better, cheaper and more available hardware, software, infrastructure and data, into products, services and new market opportunities.

All machine learning and AI-systems today pertain to weak AI. They can perform single and rather narrowly defined tasks, and we are far today from artificial general intelligence. Some first steps are being proposed, addressing the combination of learning and reasoning, multi-task and multi-modality learning, as well as life-long learning. There is a long road ahead, scientifically speaking, for instance to reach commonsense reasoning, but we should nevertheless already consider the moral and ethical implications of research aimed at AI systems that display the full spectrum of human intelligence (including consciousness).

Machine learning has recently revolutionised various fields of science and has also started to pervade commercial applications in an unprecedented manner. Machine learning has evolved into well-founded principles and software suites to support it, and learned from data, where most of the impact is still ahead of us. Deep learning describes a set of techniques that, in a supervised setting, take as input raw large datasets as they are observed with the desired outcomes and learn how to predict that outcome for unseen cases, and is one of the most prominent methods today.

At the same time, automated reasoning forms the basis for the correct and trustworthy operation of all modern computer hardware, and increasingly, also of software. AI optimisation techniques are widely used to ensure efficient use of resources in business, industry and public administration. These developments are certain to increase in impact as all of these areas of AI are developed further.

AI in Context

While the field of artificial intelligence (AI) has a rich history of more than 60 years, it is over the last decade or so when major success has been achieved. While each of AI's various subfields have seen essential developments, external factors have played a role. These include the emergence of better hardware, the internet, mobile phone networks, cloud computing, and containers. It also includes an impressive growth in the production of digital data and access to them; as well as a substantial democratisation of technology driven by falling prices, miniaturisation, advances in human-computer interaction, and available software tools and components; examples also include the significant ease of deployment as society and its infrastructure have become increasingly digitised. Another key to the recent success of AI has been on the demand side. As society's grand challenges are becoming increasingly pressing, from resource limitations, climate change, pandemics, and unstable global financial instruments, to autonomous weapons, security and migration pressures, scientists are asked to help.

While these developments give an explanation for the increased return on AI investment, and the scientific and commercial success of AI over the last ten years, they do not explain the extent of the interest in the field. The explanation for that is rather that these developments finally have brought the game-changing promises of AI within reach. Many argue that we are entering a new industrial revolution, or in an attempt to be more precise, a technology-driven societal transformation.

In this transformation, **industrial sovereignty** is at stake. Recent geo-political developments have demonstrated once more that industrial sovereignty must be a cornerstone of Europe. It is upon sovereignty that a European ethical approach, that is human-centric and trustworthy, can be built. For AI, sovereignty is not a simple thing to achieve, as both digital data and digital products are boundlessly fleeting over the world. AI-services can be run from everywhere to everyone. These services are accumulating data we have handed over, for others to use AI-technologies to draw strategic consequences. At one point in time this digital-data-trade-deficit may come back to Europe. Then, close ties of fundamental AI research and development to EU-based manufacturing and EU-based service industries to reduce the need to separate data from the product.

Technology has always defined the reality we live in. AI turns this definition, this impact on the way we live, work and think, even deeper.

While major nations across the world are significantly investing in AI, **Europe is facing major barriers** in embracing it. First and foremost, AI is driven by talent. However, Europe seems to have difficulty retaining top talent in European institutions and industries alike. Salaries are not competitive, risk capital is sparser, and scale-up competence even sparser. There is a less fluid relationship with industry. AI technologies have considerable potential to disrupt existing markets. Increasing the entrepreneurial capacity and volume is therefore a crucial element in the AI landscape. However, there is considerably less private capital and competence available for starting and scaling up new enterprises. And there is a lack of critical mass in research and connection to fundamental research such that technology-driven economic and societal impact lags behind other continents. If Europe does not embrace AI, it will come from the other two continents as AI is boundless.

The abundance of **digital data** in combination with learning have redefined the relationship of industry to society and vice versa. In the new territory of privacy law, Europe has defined the General Data Protection Regulation (GDPR) as a first attempt to protect personal digital data. In a new departure for tax law, several states in Europe are considering taxing digital data. The European parliament has accepted a motion to curb personalised advertising on the basis of data derived from cookies and the like. It is evident the landscape is changing fast, and that these elements cannot be set apart when considering AI-technologies.

The objective of many AI-systems is the taking of an action. Actions can be physical as in

robotics, where machines construct a product, or they fulfil a task in logistics. And actions can be non-physical as in search robots, gathering information from across the Internet. As for AI, the underlying principles, whether the action is physical or non-physical are the same: AI-algorithms reason towards goals.

Economically, a key competitive factor in the success of the EU is how quickly Europe will be able to use data broadly and efficiently. Trustworthiness is a crucial aspect of that. Learnability is another aspect, already essential in some B2B-applications in Europe. For some applications, trustworthy and human-centric machine learning and decision-making, including transparency, fairness and explainability, are important. For all of this, talent is the main driving force – for industry, academia and public administration. Even for societal impact, talent is key.

AI has emerged with the power **to innovate the systems of industry and society**. It is hard to decide which **new application areas** will show up over the next ten years. Generally, we will see that the potential range of AI-based systems and products is as broad as the range of human activities. We find systems or products in areas as different as cybersecurity, transportation, emission reduction, efficient use of resources, autopiloting, robotics, gaming, finance, marketing, industrial production and public administration. It follows that AI is not a technology or field of science, but rather a broad range of research and technologies with an unusually wide range of applications.

Europe's future, its ability to tackle environmental and societal challenges while also strengthening European competitiveness and positioning the continent in the global knowledge economy, is dependent on its ability to establish well-functioning ecosystems of research and innovation. Successful ecosystems have strong collaboration between different sectors, including businesses and industry, entrepreneurs and startups, investors, academia, and governments.

Many **start-ups in AI** originate from academia, some of them will grow fast. A fascinating new phenomenon is that in AI and in machine learning, the borders between academia, industry and services are transforming. Europe trails behind in this respect in what other continents are achieving. To stem the data and brain drain, Europe needs to put talent first, start-ups and scale-ups need to be fostered, services and industries need to be helped to adopt and make efficient use of the new technology, and societal concerns need to be dealt with at the core of the technology. All of this is needed to provide economic stimulation, and to ensure European technological sovereignty.

The most important aspects of a European policy for excellence in AI would cover regulation, infrastructure, the ecosystem, industries, and public opinion. Europe's capacity for achieving technological sovereignty critically depends on creating digital infrastructures and managing holistic value chains, with the goal of supporting the creation, deployment, and commercialisation of Europe-developed AI-methods and technologies. There is an increased need for speed on a standardised regulatory framework, infrastructural self-sufficiency, a vibrant and multilateral ecosystem, and the support of public opinion.

Fast and safe development of coherent and consistent regulation of data, AI and robotics is a condition for technology-driven growth in Europe, e.g the General Data Protection Regulation. Clearly, regulation is important for clarity and the protection of citizens' rights, but at the same time, Europe needs to be mindful of the consequences of over-regulation. Legislators need to carefully balance the need for protection of individuals and the societal benefits of software systems. However, regulation and ethical guidelines for AI should be lean enough to not undermine societally beneficial products and systems and the development of commercial AI in Europe, whether in large industry, SMEs or startups.

On the one hand, demanding controlled AI while on the other not providing a complete and practical legal framework breeds distrust in AI among the general public, as well as investor uncertainty. Legal sandboxes are instruments intended to make early pilots possible, long before regulation is in place. These combined tech-legal workspaces should facilitate participation for startups as well as established and large companies. Other specific suggestions include regulation of the data economy; privacy standards; best practice recommendations; standard practices for data collection; emphasis on faster algorithmic development to keep up with the other continents; more attention to fostering talent to keep up with the other two continents; accepted itemisation of 'types' of AI to prevent over-regulation; and certification, watch-dog and validation standards.

It is important that we ensure that Europe has well-functioning and efficient market mechanisms. Other economic regions have moved early and put the market mechanisms under pressure. The market opportunities of AI and machine learning are so big that particularly focused efforts on keeping the scientific and commercial talent here are needed by creating opportunity in data and in knowledge foci. Creating a permanent Network of Excellence beyond national borders and within top-research institutions, as well as multilateral collaboration between industry and research organisations that utilises the rich, industrial data available to solve real industry problems. This is also a mandatory element in the adoption of universal standards and practices, in the encouragement of new industries to adopt AI, and in the alleviation of the costs of development and research for startups and SMEs.

Over-regulation could easily prevent startups from penetrating the market and give a global market advantage to companies based outside of Europe. And the lack of common digital infrastructures means that they do not have access to appropriate and affordable datasets and processing power. Similarly, Europe is lagging behind in its capacity and competence in scaling technologies and companies. Without a market that is willing to take risks, and without significant collaboration or channels of communication between industry and research, talent seeks its opportunities elsewhere.

Market Perspectives of AI

In a recent communication by the European Commission [1], a Europe-wide survey was conducted on the **uptake of artificial intelligence** among enterprises. In early 2020, the survey reached a total of 9640 enterprises. It measured a high awareness of AI for three quarters of all enterprises, where half have adopted at least one AI-technology and a quarter have adopted two or more. In fact AI-adoption was found to be highest in the ICT and finance sectors while it was low in construction. While one in five have plans to adopt AI in the next two years, two in five have neither adopted AI nor plan to do so. Adoption at the level of each technology is still relatively low: from 3% for sentiment analysis to 13% for anomaly detection and process or equipment optimisation. The most common sourcing strategy is external, as 60% of EU-enterprises that use AI purchase software or ready-to-use systems. For half of all enterprises, key **internal** barriers to AI-adoption are difficulties in hiring new staff with the right skills, the cost of adoption, and the cost of adapting operational processes. One third of all enterprises find liability for potential damages, data standardisation, and regulatory obstacles, to be major, but less important, **external** challenges to AI-adoption.

The study demonstrates the importance of the AI-wave of innovation as it goes through three quarters of all enterprises in Europe. The study demonstrates that it is important to remove internal obstacles due to lack of talent, and external obstacles by providing certainty on regulation.

Industry and services now and in the near future inevitably rely on AI technology. An important driver of the current intense innovation wave is the pervasiveness of digital data. And, as a consequence of the abundancy, research in AI has emerged as a motor to drive innovation in industry and in services. The quality of that connection will determine the success of a continent in the innovation wave which is currently underway. The more industries and services rely on data, the more they need to embrace the opportunity for business model innovation as well.

Banking has been disrupted by new forms of money, new forms of payment, new forms of risk assessment, and new forms of fraud. This requires cyber-security, which increasingly is based on AI techniques, but also AI-techniques like machine learning, which are essential to predict the solvency of clients while ensuring proper fairness. New billion euro companies have grown with new business models such as specialised but grown-big fintech companies, and also big-tech have ambitions to challenge and disrupt classical models.

Retail has been disrupted by new forms of home delivery, new forms of advertising and new forms of routing. The business models of the sector are transforming themselves necessarily for survival due to the entrance of young giants as Amazon. New billion euro companies have grown and old retail is transforming itself speedily. The success in this innovation will be determined by the effectiveness of AI-techniques like machine learned personalisation under proper protection of privacy and detailed planning stock and transportation.

Restaurants and personal services are being disrupted by new forms of delivery by new billion euro companies such as Just Eat Takeaway and Deliveroo, also in response to Uber. The business models have not found an equilibrium yet, but the success in this innovation will be determined, in part, by the effectiveness of new business models integrating AI-techniques such as machine-learned and machine-optimised personalisation under proper privacy protection and detailed prediction of societal mood. From many new internet companies we have seen how a sector will be transformed by re-inventing the digital information flow coupled to predicting where and when it will be needed by AI techniques. Apart from information standards and chain normalisation this requires AI to survive.

In **medicine and care**, the integration of AI into the daily work is already on its way. This will require AI techniques for AI-assisted diagnosis, AI-based monitoring, abnormality signaling, and early warning for proper care. This will require AI technologies like deep learning, verification, and optimisation, and a deep and proper attention to personal protection deeply integrated into the technology. European companies in healthcare are transforming into AI-companies gaining experience from digital dossiers and digital medical knowledge to personalise medical care. More than in other application areas, explainability of decisions is of importance here, as well as provable safety and correctness of AI-driven systems. They will be supplemented with new companies for discovery in pharmaceuticals through reinforcement learning and other AI techniques such as, for instance, healthcare monitoring under anonymity.

Many **service sectors** rely on handling information and knowledge effectively and efficiently: notary services, law, real-estate, transport, and trade, for example. This has caused the emergence of a new sector: information search, trend prediction, and strategic information management, all based on data-driven and model-driven AI techniques together with effective techniques for optimisation and natural language processing. Where data-tech companies dominate the market, Europe cannot afford to lock itself out of this sector. We see the emergence of specialised billion Euro companies such as for literature and for judicial information services.

The above list supplements the emergence of AI in data analysis, manufacturing, mobility and transportation industry, environment and energy sectors, and agriculture where AI-branches of machine vision, human-machine interaction, planning, reasoning, quality control, and feedback are already coming into use.

Example of Areas of Work

The work of the PPP can be organised by grouping sectors of industry according to the similarity of their needs and define PPP AI-programs for them. By example, banking and the financial sector will employ AI and cyber security, large data learning, fairness in AI. Retail will need AI-planning and routing, AI and personalisation. Personal services will profit from limited personal data flows, personalisation, information retrieval. Medicine and healthcare will be boosted by AI-assisted diagnosis, privacy, small data learning, explainable AI, care surveillance. Professional services will need NLP, AI-guaranteed search, explainability, trend prediction. The newly forming sector of digital data handling will need algorithms to come to data, precise data, knowledge engineering. Manufacture and production will use action, planning, sensor data, AI quality control, autonomy. Agriculture and the food chain will employ robotics, sensor data, AI Quality control, autonomy, that will also prove crucial to smart mobility and the race for autonomous vehicles. In arts, entertainment and cultural production AI will be employed. In earth- and space science will need computer vision and trend prediction. Education and Training will turn digital and intelligent by personalisation learning and reasoning. Energy and resources will be used more efficiently by planning. The environment can be protected more effectively by modelling and planning. Information and Communication Technology will be more efficient by intelligent routing. There are many examples in public administration and citizen services and there are many opportunities being employed in science, innovation and design. Transportation will reach autonomous vehicles as only one example in that branch of the application of AI.

Framework and Enabling Factors

Commercial and scientific progress on AI is not only a function of scientific development, but on underlying infrastructure, the regulatory environment, household digitalisation, and governmental policies.

European Framework

European rights, principles, and values in AI

Responsible research and innovation. Utilising the tangible results of the Horizon2020 program in responsible research and innovation helps guide Europe's competitive effort in the field of AI towards socio-economic benefits in Europe, democratic development, rule of law and human rights.

Trustworthy AI. The European Commission, building on the work of the High-Level Expert Group on Artificial Intelligence, is focusing strongly on the development of Trustworthy AI. In their recent Whitepaper on AI they further built on this concept with a vision for regulation in AI. Trustworthy AI systems must be ethical, legal, and robust. A framework of seven key requirements have been developed to characterise the notion of trustworthiness more precisely.

Explainable AI. It is generally accepted in both research and industry that explainable AI is an important element. In the public debate on AI, it dominates as a way to enforce a reasonable and ethical version of AI. Explainable AI is necessary to engage the public in the debate of the values, changes and opportunities AI brings, and explainable AI is sometimes an essential element by itself. There are also large sectors of society where explainable AI does not play a role. When the performance of an AI-application is predictable or the application is under strict human supervision or the application has no societal harm, the most accurate result will prevail and rightfully so. In manufacturing, a key asset of Europe's economy, the best performing AI algorithm will generally win. Enforcement of explainable AI should be differentiated to the use and goal of the application. Where explainable AI is needed, a tendency is observed to equate explainable AI with symbolic AI as if only explicit rules can deliver explainability to AI. There are other ways of explanation: by visualisation, by visual examples as is the preferred way of teaching in medical radiology, by circumscription of abstract notions such as "justice" or "relevance". It is important to assess where explainable AI should be enforced and what are the permissible ways to achieve that.

Promoting value for business, society and people in AI

AI for good. In order to strengthen political support for AI in Europe, it is useful to focus the European strategy on how AI can be used for improving people's lives. AI for good is employing AI to tackle some of the world's greatest economic and social challenges, AI for All. Global leadership in this focus can make the term "AI made in Europe" synonymous with commercial products and services bringing AI for good. Again, the European focus here is on Trustworthy AI (as discussed above).

AI-innovation ecosystems. Strong AI-innovation ecosystems are a prime enabling factor. When looking around the world, global success in AI requires that all parts of the AI-ecosystem are well developed and interconnected: entrepreneurs, innovators, investors, regulators, large and small enterprises, and applied and foundational scientists and research teams. Innovation happens increasingly as non-linear interactions between the actors in the ecosystem (in contrast to purely linear technology transfer from university to industry), a development shift that is strengthened by AI.

Academic collaboration with industry. It is critically important that industry-academic collaboration is encouraged and structured using transparent and simple IP rules that ensure that public funding is used in a way that benefits the public. Joint research involving industry and public funding should be published openly. Crucial in AI and especially to stimulate an active start-up culture. AI researchers should be encouraged to establish startups. The emphasis should not be on the optimisation of short-term licensing income but be aimed at sustained impact, thus generating downstream impact in Europe. We should facilitate startups in many ways.

Policy, regulation, certification and standards in AI

Regulation and market. Competitive use and uptake of AI need both regulation and functioning market structures. Clearly regulation and policy instruments can both hinder and advance Europe's AI developments, including markets, new research, and applications. However, it might also become an advantage for European industry having anticipated new regulation.

Regulatory sandboxes. The European Commission, the European Parliament, and various national AI strategies have recognised regulatory sandboxing as a strong enabling factor for technologies and, most prominently, AI.

Governmental funding instruments. With weaker private investment in AI in Europe, governmental funding instruments become that much more important. The European Commission and the Member States are working through a framework envisaged in the Coordinated Plan for AI1 that ensures alignment between Member State strategies in AI. The PPP will provide an important level of complementarity to those efforts by connecting and supporting the Commission's Digital Innovation Hubs, and opening them up to the wider European AI innovation ecosystems.

It is critically important to incentivise and support interdisciplinary and multi-stakeholder research, for example through large-scale challenge-driven research missions. However, Europe should also consider simplifying and streamlining the structure of research funding instruments, and reduce the overhead in terms of effort and time to apply and manage grant funding, while not compromising on quality or accountability.

Privacy and safety by design. Research and development in the areas of privacy- and safety-by-design in the last two decades provides a market opportunity for European businesses. Such a position can be strengthened by recent work in ethics-by-design for AI. The European view for digital privacy, as currently regulated in GDPR, is a good first step. A commonly feared weakness would be if regulation separated from the AI technology, opening the door to circumvention so that there exists an easy workaround of the regulation. Privacy and ethical considerations, in general, can best be studied in connection to developing the best techniques of AI. An opportunity would be to integrate privacy into the machine learning technology, for example by the application of a cryptographic technique, now popular in machine learning, known as differential privacy, aiming to guarantee an explicit and limited list of conclusions to be allowed from data, or by applying watch-dog technologies.

Data accumulation. Too little attention has been paid in society to data accumulation and the dangers it brings, especially when data are transferred to other continents. Accumulation of data from all corners of life is an unrated weakness of our current digital world as it could easily jeopardise the anonymisation of data as framing would easily fill back in the name and other ID-information removed from the data. Another approach to put limits to accumulation is federated machine learning, applying algorithms to the data to learn without the need to first centralise sensitive data and still learn for a specific purpose. Therefore, Europe would want to endorse the ethical, defensible, data accumulation and privacy constraints in close combination with the further development of the AI-technology. On the other hand, free flow of data is also of paramount importance, since startups usually have a global mindset from the get-go.

Data localisation measures are hindering this flow by dictating in which jurisdiction data should be stored or processed. However, localisation is not necessary for protection, and so it imposes burdensome restrictions to startups while not ensuring that data is safer.

Regulation and certification of AI. Regulation by means of developing standards, metrics, legislation and institutional mechanisms for auditing, monitoring, inspection and certification, is an important context for Europe's AI strategy. Regulation can, when designed appropriately, boost European competitiveness. In regulation, verifiable AI is important. It is a natural task for the EU to regulate. It is important to certify machine learning in safety critical systems on safety integrity levels (SIL).2 Being able to certify the safety level offered by any machine learned or complex knowledge-based algorithm has great impact, possibly more impactful than explainability of its decisions. The alternatives of formal methods of verification are intrinsically difficult to generalise to data-heavy applications. Considering that Europe's economy is significantly based on building machines, from automotive to industrial robotics and manufacturing in general, and considering that putting AI into these machines would likely have a strong impact on the EU economy. The AI, Data, and Robotics PPP, and AI4EU, could play a role here. An opportunity arises for Europe to stimulate good methods and procedures for verification, which for machine learning would surpass formal methods of verification and include methods, which can handle external (training) data.

Innovation Enablers

Skills and knowledge

First and foremost, talent will enable the growth of AI, as was also found in the recent study on AI-adoption[44]. The spread of fundamental knowledge is essential for the continent, within academia and across to industry and back. Cross-visiting researchers between academia and industry as well as workshops and summer schools for students, academics, and industrial participants help to promote mobility, facilitated by housing, childcare, and international schools at each site. AI "made-in-Europe" is equivalent to fostering talent to stay in Europe and pursuing competitive AI research at the world-level with best opportunities for societal and economic impact. Investment in AI talent is not a free choice. When first talent, and then data of all sorts, are shipped to other continents, one day this will have consequences for the AI models that will make our economy, culture and society efficient, in order for Europe to have a say in the values important to her.

Europe requires dedicated efforts in establishing cross-disciplinary AI curricula in tertiary and post-graduate education which integrate ethics, humanities and technical disciplines, in mainstreaming AI-related skills in all academic disciplines and professional fields, as well as in fostering cooperation spaces between AI experts and professionals. Education is fundamental. Europe already has a good educational system that can be further improved. First, there is a need to significantly increase the volume of broad AI educational programmes with a focus on technology (at all levels including BSc, MSc, PhD, and postdoctoral). Second, Europe must develop specific AI educational programmes with a focus on dissemination in other sciences and society as a whole (at all levels including BSc, MSc, PhD, and postdoctoral). Third, Europe must make sure that primary and secondary education provides the necessary theoretical and practical foundations to allow everyone to become active and engaged citizens in the modern society, where AI is a natural part.

44 "European enterprise survey on the use of technologies based on artificial intelligence", 2020, the EC.

Fourth, Europe should develop and implement a model curriculum of its own in AI.

Data for AI

Data. The significant increase in data volume will continue. Europe's data production does not guarantee global competitive strength in itself. Strong enablers to AI include providing access to data and data feeds from the increasing number of data producing objects in society, regulate its use, and develop functioning data markets. First, an incredible amount of useful data is created and retained nationally by public institutions. This data can spark innovative breakthroughs in various sectors. It is important that Europe's governments move towards making substantially more of their data available, and make test or prototyping data freely available. For data-driven companies to emerge and flourish a well-functioning data market would be a strong enabler. In such a market, there are both producers of data, refineries known as data factories, and companies turning refined data into products and services.

The construction of **pan-European data infrastructures**, such as the proposed European Data Space, may be an opportunity after taking special attention for its suitability in AI-development and AI-research. A data infrastructure might be considered the best mechanism to build sovereignty in AI in Europe as for machine learning the data to a significant extent determine the outcome. For health, but also for all other sorts of relatively rare data resources, coping with data without accumulating them, and respecting privacy, may be key.

Experimentation and deployment

AI-chips and **microprocessors** refer to a new generation of microprocessors that are specifically designed to process artificial intelligence tasks faster, using less power. AI chips are expected to play a critical role in economic growth because they will provide advanced AI processing for mass-market AI apps and move AI capabilities to (increasingly smarter) cars, homes, robots, manufacturing chains, weapons, electronic devices, and all sorts of things connected to the internet.

The **5G-mobile network** is expected to speed up a move of AI computations from the cloud to the edge or IoT devices, in addition to next-generation edge computing convergence with AI systems on chip: 5G will enable edge devices to seamlessly move between indoor and wide-area environments. These same 5G interfaces will undoubtedly be converged with neural network processing circuitry.

AI-targeted **high-performance computing**. High-performance AI is dependent on high performance computing. However, the requirements for high-performance computing infrastructure in AI is markedly different from those in traditional areas of high-performance computing, involving specialised hardware architectures. Also, while AI services need to be developed, deployed, and shared across a large variety of computing environments, we assume Europe will establish an increasing number of large-scale AI projects that will need support from larger regional or even European infrastructures.

In Europe, diversity coupled to language is natural. It should be part of any strategy as it provides a natural advantage. In Europe to achieve some form of technology sovereignty, a necessary condition is an infrastructure, for data as well as for the processing. The data would require further elaboration on common European data spaces with the effect of a de-facto European standard; data collection standards; privacy-preserving and anti-data-accumulation data sharing infrastructures; and open-source data lakes.

At the same time, the infrastructure "proper" should be held "in common": for model testing with a small-effort to transition to certification; built upon European computing (cloud) infrastructure as an alternative to AWS; algorithm development sovereignty; sector-by-sector endorsed development of European web-engines; language translation technologies.

Other infrastructure components would address the need for achieving stronger cohesion across Europe's scientists and AI ecosystems. While Europe has many of the world's best AI scientists, they are spread out across many countries, research centers, companies and projects. Two possible instruments to counteract this, as proposed by the Commission in its Whitepaper on AI, are a network of AI centers across Europe and a European "lighthouse".

Possible Programs

The PPP will develop a number of co-funded programs. Here follows some examples of possible programs. Ensuring the trustworthiness, correctness, safety, leveraging European strength in automated reasoning. Developing the role of AI in resource allocation, efficiency of services and use of resources, leveraging European strength in AI planning, scheduling, optimisation. Dealing with multiple, conflicting objectives and preferences, between humans as well as between AI agents, leveraging European strength in multi-agent systems. Talent scouting, training, exchange, encouragement inEU across the border of academia – business including start-ups and scale-ups at world level. The accumulation of personal data is undermining proper privacy even if protected. New regulations beyond GDPR need to include technology like differential privacy. Explainable when necessary explain decisions: by example, text, or visualisation. Certification and/or watch-dog technology needs to be set up: practical procedures and standards how to do it efficiently in practice.

Technology Enablers

A weakness in Europe is that the discussion on AI has become very siloed. Contradictions have been created between symbolic AI and machine learned, data-driven, and bottom-up AI, between sensory data knowledge versus real human knowledge, between humane AI and not-so-humane AI. In the end these oppositions are not fruitful nor will survive history. Therefore, Europe should work on obtaining basic and fundamental knowledge in AI without prejudice for the technology. And, Europe could work on the integration of the valuable elements of symbolic and learned knowledge without denominating either technology as humane AI.

Sensing and Perception

Digital sensory information was used for efficient recognition until machine learning provided the first application areas where the machine has reached a human-level recognition of what is seen. The same holds for aural and spoken understanding of text. Well-trained machines provide a level of advice on dermatologic disorders compatible to the best human performance. The same holds for a broad range of ophthalmic diseases. In manufacturing and agriculture, visual quality control and anomaly detection is on the verge of being standard. New businesses have been built on the automatic reconstruction of 3D space from camera recordings. Diverse activity recognition will find its application in surveillance in a broad range of industries, camera-assisted care, quality inspection, numerical assessment of quantity, and autonomous vehicles.

Geometric Deep Learning is crucial to topics as diverse as the analysis of social interaction and its consequences for the prediction of fashion and societal moods, protein-protein interactions in biochemistry for drug design, bonds between atoms within molecules in material strength, and robustness of planning transportation in road networks. Anything where links between entities is the crucial aspect. Recent years have seen a surge in the deep learning of graph-structured data capturing larger and wider structures in their analyses.

Robot Learning. Effective learning of actions and controls from the right amount of data and instruction for real-world robots aims at significantly improving robustness and flexibility of robots that interact with the real world. Machine learned robots will, in the end, be able to cope with changing environmental conditions. Not only will this enhance the robustness of the robot but also its precision and its capacity of collaborating with a human user. How should the robot move? How to act? How to interact? The application in manufacturing, agriculture but also in surgery has only just begun.

Data, Knowledge and Learning

Machine learning is concerned with algorithms that modify their own behavior based on observations, that can be examples or results of the program's actions on the world. In the former case, also known as statistical learning, the goal is to build a model of the concept under study from a dataset of examples. Within the 'learning from examples' paradigm, one usually distinguishes supervised learning, in which examples are labeled with the target concept (which a category for classification problems, or a continuous function, for regression problems), semi-supervised learning, where usually only a small fraction of the examples is labeled, and unsupervised learning, in which no example is labeled, and classes/outputs need to be identified as well. When the observations are results of the program's actions, reinforcement learning aims at identifying the best policy choice of action depending on the state of the system) in order to optimise some external reward resulting from its actions. Other systems are for instance recommendation systems.

The most well-known approaches to-date in machine learning, that are responsible for the recent successes of AI are based on deep neural networks. It has resulted in a world-wide dissemination in computer vision, signal processing, natural language processing, where new application domains appear continuously. Neural networks have revolutionised supervised learning as well as reinforcement learning, because they perform end-to-end learning: not only do they not require any human-designed features to describe the data, but they actually build such representations of the data, oriented toward the task at hand. This allows building powerful generative models known as GANs. Subjects of current cutting-edge research: robustness against adversarial examples, detection and correction of biases, and explainable machine learning for trust; transfer learning, domain adaptation, and few-shot learning for small-data contexts.

Although contemporary machine learning algorithms achieve fascinating results even at the borders of human performance, they often remain inefficient, unreliable, brittle, or require manual tuning. Many contemporary machine learning algorithms are still comparably badly understood. As a result, they require manual tuning, can be inflexible and sometimes behave erratically. And there are essentially new elements to the machine learning tree: causal reasoning of learned systems and reinforcement learning where the reward not the label determines the capacity to learn. The development of efficient and reliable learning systems with theoretical guarantees is in order. One particular form of AI Is automation of AI including the choice of algorithms and parameters and configuration in the search community. The main challenges ahead are the identification of descriptive features of datasets in an ML-context or problems in search that would allow instance-based automatic configuration.

Robust Machine Learning. As machine learning technologies are progressively deployed across the sciences and into the real world, it is becoming more important that they can reliably perform well, when applied in settings different to those during training. One set of techniques applies adversarial manipulations during training to make the classification robust. Another set of techniques solves learning when only unbalanced, messy or heterogeneous data are available. Applications range from medicine where data are scarce, fault detection in industry where data are intrinsically unbalanced, environmental sciences, in manufacturing for assisted design, the robustness of autonomous vehicles and industrial control to handle also unseen situations.

Reasoning and Decision Making

Reasoning is any way to infer rational conclusions or making reasonable predictions from available knowledge. Also, for reasoning to be meaningful in addition to correct, it needs to be relevant to any situation at hand. Symbolic reasoning involves the explicit embedding of human knowledge and reasoning into computer programs. Sometimes they are embedded in software systems, sometimes they are components of technologies known as for instance knowledge-based systems, knowledge graphs, ontologies and semantic web, expert systems, and logic programming. Reasoning methods such as constraint solving, model checking and automated theorem proving, and methods from SAT and SMT solving, are today widely used for hardware design and verification, software verification in mission-critical systems, planning and scheduling of a number of industrial tasks like robots, air-traffic control, traffic routing, industrial automation. The systems are used to both design by verified synthesis and certify real-world complex systems, both human-designed like air, train and car control systems, stock-trading systems, and automatically designed such as neural networks and other results of machine-learning algorithms used in industry, putting formal guarantees on their use. Reasoning might, of course, be distributed across multiple agents, which might also introduce complex strategic and game theoretic dimensions, as well as issues such as self-interest and the importance of incentives.

Formally verified software and hardware stacks include operating systems, compilers, drivers, industrial encryption schemes. Such components are becoming critical and preventing billion-scale damages resulting from hardware and software bugs, expensive system malfunction as in Mars-landers, and today's wide-scale hacking attacks on practically arbitrary parts of industrial, economic, governmental infrastructure in banks, hospitals, and the military.

Search and optimisation in AI. AI-based search methods include a large variety of techniques to solve tasks and find solutions to optimisation problems that are ubiquitous both in industry and the public sector. Examples include minimizing energy use, waste, emissions, and cost, drug development, optimizing telecom bands, logistics, supply chains, crew rotation, scheduling, resource use like the use of health care resources during crises, and the use of expensive equipment, like MRI-machines and image and communication satellites. Many of these problems are specialisations of research areas in AI, like the travelling salesman problem, quadratic assignment problem, vehicle routing, as well as their numerous variants on costs and time windows. AI-based search methods pertain to such challenges, which, depending on their nature, are known as combinatorial or continuous optimisation problems. AI approaches for combinatorial optimisation include constraint programming, AI-planning and scheduling, and are close to reasoning methods. Metaheuristics are more general problem-solving techniques that can be adapted and applied to create new market opportunities and handle the increasing complexities of our modern digital world. Several metaheuristics are inspired by nature, in evolutionary computation, simulated annealing, or swarm optimisation approaches. They are increasingly applicable and powerful for real-world problems as for instance the ones listed above. These methods are important both for improving global competitive positions for Europe's highly capitalised industries, increasing efficiency in its public services, and meeting the grand challenges of our time.

Action and Interaction

AI has traditionally focused on full automation, where the computer completely solves a problem without human interaction. However, there is evidence that rather than replacing humans, a better approach is to design systems which allow humans and AI-tools to collaborate effectively. It is also the case that even if a taxi drives completely autonomously, it still needs to interact with the passengers. Effective human-AI collaboration relies on techniques such as natural language understanding, gesture and activity recognition, understanding intention, creating and maintaining shared mental models, and interaction design. This is also an important aspect of maintaining meaningful human control through for example human-in-the-loop, human-on-the-loop and human-in command.

Interactive learning. Machine learning has an excellent capacity of reproduction of the given samples. It does not immediately provide a cause of the automatic conclusion. For a deeper understanding as may be needed in diverse professional services as law and finance, interactive and multi-agent learning and causal modelling are important for acceptance matching the overstressed expectation of robust intelligent behavior attributed to AI. These techniques will be important for high-stake real-world applications.

Human-centric machine learning. As the use of machine learning becomes widespread in human-centric applications and algorithmic decisions are more consequential to individuals and society, key limitations of today's machine learning systems need to be identified and presented in the result. Algorithmic discrimination against minorities, manipulation of human decision-making, the spread of misinformation and the increase of polarisation, are simply impossible to tolerate. In the end, it will require close cooperation between regulation and the development of technology to achieve this at the intersection of machine learning, causality, human-computer interface, differential privacy, and computational ethics. Transparency, accountability, interpretability and fairness of the algorithmic decisions, amenability to legal and technical certification, accountability and verifiability are all relevant here.

Explainable AI. Evolving AI-techniques and AI-based systems from black boxes, which they largely are today, to techniques that can complement the decisions they reach with machine- and human-understandable explanations as to why each specific decision was reached, is a necessity for extending the application domains of AI to any domain where machine-human synergy or the accountability of AI are of importance in medical diagnosis, autonomous driving, smart farming, media verification and fact-checking, to name a few. This involves not only focusing on AI-based techniques that can inherently provide some evidence on the decisions they make reasoning systems, or simple versions of deep learning architectures comprising just a handful of layers where some sense can be made as to how the network works, but more importantly focusing on the fundamental issue of how to endow with explainability properties the most complex of the present and future deep learning architectures that can provide state-of the-art results and will be deployed in real-life applications. Explainable AI comes in many shapes and forms: textual explanation, explanation by example, visualisation of the decision space, rendition of the decision loop, uncertainty expression.

Systems, Hardware, Methods and Tools

To develop truly intelligent systems, many different AI-components need to be integrated into working systems with system properties and system guarantees. Developing a science for designing, analyzing, operating, monitoring, maintaining and extending AI systems is therefore greatly needed. This would complement the impressive progress in developing individual AI algorithms and components. This area is closely related to robotics.

On **hardware and software infrastructures,** deep learning comes with a need for GPU-clusters, publicly available software resources such as Github and publicly available software suites such as TensorFlow, Caffe and Pytorch. These toolsets have substantially contributed to the current wave of deeply learned AI as they have widely spread modern technology at a rapid pace. As to the necessity of developing hardware in Europe, there are two different, almost orthogonal directions: on one side as the size of data will grow, there will be a need for machine learning and large-scale knowledge AI-algorithms to scale up to exascale machines. On the other side, latency issues will make it essential to use edge solutions, which means deploying algorithms on limited computational resources, and adapting algorithms to small sample sizes and domain generalisation and federated or privacy-preserved learning.

Possible Programs

The PPP might focus on a number of co-funded trans-sectoral programs in areas such as the following. Learning reliable AI for banking, medicine, agriculture, professional services, remote sensing, chemistry, social media trend prediction, manufacturing, etc. Learning over multi-modal data (vision, audio, speech, etc.). Learning in the context of time series data, including anomaly detection. Robust AI, including planning and interaction between agents, as one of the most important aspects of trustworthy AI, applies to all application domains. Interactive AI, leveraging humans in the loop, and human-centric settings. AI for earth and space science, sustainability and environment. Automated reasoning for provably ensuring safety and correctness of hard- and software systems in critical applications in areas such as transportation, healthcare and finance. Next-generation robotics, with an emphasis on learning from small and large data, robustness, safety, correctness, efficiency and flexibility, with applications in healthcare as well as industrial and food production. Next-generation transportation systems across all modalities.

DATA DEEP DIVE

The European Strategy on Data identifies them as an essential resource for economic growth, competitiveness, innovation, job creation and societal progress[45]. Global investments in data-driven innovation are expected to rebound strongly from 2021 onwards, after the slow-down caused by the Covid-19 pandemic in 2020. IDC[46] forecasts worldwide investments in Big Data & Analytics to reach 294 B€ by 2025, of which 16%, corresponding to 47 B€, generated in the EU27. If we consider the overall impacts of data-driven innovation, IDC foresees growth of the EU27 data economy[47] from 397 B€ in 2020 to 510 B€ by 2025, in a baseline scenario, with the potential to reach more than 800 B€ by 2025 in the high growth scenario (if, for example, the investments are driven by the EU New Recovery Fund effectively accelerate innovation and growth). The European Data Market Study[48] reports on the significant expansion of the European data economy in recent years:

- The **number of Data Companies** increased to 290,000 in 2019, compared to 283,300 in 2018.
- The **revenues of Data Companies** in the European Union reached 83.5 B€ in 2019 compared to 77 B€ in the year before, with a growth of 8%.
- The **baseline for Data Professionals** in the European Union in 2013 was 5.77 million. Their number increased to a total of 7.6 million by 2019 in the EU28, corresponding to 1.836 million jobs created for data professionals since 2013.

Data Growth, Value Opportunities

A critical driver for emerging AI and data-driven business opportunities is the significant growth of data volume and the rates at which it is generated. By 2025, there will be more than 175 zettabytes of data[49], reflecting a five times growth of data from 2018 to 2025. In parallel, we are assisting to a shift of data to the Edge and cloud environments. While, in 2020, 80% of processing and analysis takes place within data centres, the transition is on to more data being processed at the Edge of the network in smart connected devices and machines. By 2025, IDC predicts that 46% of the world's stored data will be in public cloud environments[50]. This creates new opportunities for Europe to lead this form of data processing and for European actors to maintain and control the processing of their data. As EU Commissioner Thierry Breton stated, "the goal is to prepare ourselves so the data produced by Europeans will be used for Europeans, and with our European values."

Benefits for the Economy, Business and Society

Data enables AI innovation, and AI makes data actionable. Data flows link together the emerging value chains improved or disrupted by new AI services and tools, where new skills, business models and infrastructures are needed. The data governance models

45 European Commission, "The European Data Strategy," 2020.
46 IDC, Worldwide Big Data and Analytics Spending Guide, Forecast, August 2020
47 The European Data Market study Final Report, 15th May 2020, http://datalandscape.eu/study-reports
48 The European Data Market study Final Report, 15th May 2020, http://datalandscape.eu/study-reports
49 Data Age 2025, The Digitization of the World From Edge to Core, data refreshed in May 2020, https://www.seagate.com/files/www-content/our-story/trends/files/dataage-idc-report-final.pdf
50 European Commission, "The European Data Strategy," 2020

and issues such as data access, data sovereignty and data protection are an essential factor in the development of sustainable AI- and Data-driven value chains respecting all stakeholder interests, particularly SMEs. The latter are currently lagging in AI adoption.

AI and Data innovation can generate value not only for business but also for society and individuals. There is increasing attention to AI and Data potential for social good, for example, contributing to achieving the UN social development goals and the environmental goals of the EU New Green Deal. Enterprises are developing sustainability programs in the context of their corporate social responsibility strategies, leveraging Data and AI to reduce their ecological footprint, cutting costs and contributing to social welfare at the same time. Public authorities are also looking into ways of unlocking private data for general purposes. Business and social value can be pursued at the same time, encouraging the re-use and sharing of data collected and processed for AI and Data innovation (sharing private data for the public good, B2G and not only B2B). Expertise is needed to increase awareness about the potential value for society and people as well as the business of data-driven innovation combined with AI and use this assessment to prioritise public funding.

High-level Europe Opportunity and Challenges

For the European Data Economy to develop further and meet expectations, large volumes of cross-sectoral, unbiased, high-quality and trustworthy data need to be made available. There are however important business, organisational and legal constraints that can block this scenario such as the lack of motivation to share data due to ownership concerns; loss of control; lack of trust; the lack of foresight in not understanding the value of data or its sharing potential; the lack of data valuation standards in marketplaces; the legal blocks to the free-flow of data and the uncertainty around data policies. The exploration of ethical, secure and trustworthy legal, regulatory and governance frameworks are needed. European values, e.g., democracy, privacy safeguards and equal opportunities, can become the trademark of European Data Economy technologies, products and practices. Rather than be seen as restrictive, legislation enforcing these values should be considered as a unique competitive advantage in the global data marketplace.

Data spaces, platforms and marketplaces are enablers, the key to unleashing the potential of such data. Significant technical challenges such as interoperability, data verification and provenance support, quality and accuracy, decentralised data sharing and processing architectures, and maturity and uptake of privacy-preserving technologies for big data have a direct impact on the data made available for sharing.

Alignment and integration of established data-sharing technologies and solutions, and further developments in architectures and governance models aiming to unlock data silos, would enable data analytics across a European data-sharing ecosystem. This will allow AI-enhanced digital services to make analysis and predictions on European-wide data, thereby combining Data and Service Economies. New business models will help to exploit the value of those data assets through the implementation of AI amongst participating stakeholders including industry, local, national and European authorities and institutions, research entities and even private individuals.

Role of the Partnership in the European Data Strategy

The European Data Strategy sets out a vision for the EU to become a role model for a data-driven society and to create a single market for data to ensure Europe's global competitiveness and data sovereignty[51]. As highlighted by Breton "to be ahead of the curve, we need to develop suitable European infrastructures allowing the storage, the use, and the creation of data-based applications or Artificial Intelligence services. I consider this as a major issue of Europe's digital sovereignty." The Partnership will be a key enabler providing the strategic research and innovation activities needed to realise its vision. It will enable the EU to have a leading role in the data economy and to develop the key legal, social, innovation and technical enablers needed to ensure its adoption. Our vision for the role of data in this Partnership is detailed below.

European Data Framework

European Fundamental Rights, Principles and Values

The availability of and efficient access to high-quality data is essential to harness the full potential for creating social and economic value. It remains a significant challenge to guarantee the necessary levels of protection of fundamental rights and corporate interests and to safeguard the European market competitiveness. As data is essential for all economic actors, access to data should be inclusive, not in the least for SMEs. Data-sharing mechanisms, the flow and wide use of data must be balanced with high privacy, data protection, security, safety and ethical standards[52]. Unlocking data with a high societal value should be further explored. More possibilities can be created, for example, for relevant data to contribute to the green transition and digital transformation and towards the realisation of the UN Sustainable Development Goals.

AI and Data require new attention to ethical constraints in decision-making by autonomous systems when applied to sensitive domains such as policing, justice and education. More attention should be paid to the quality and type of datasets fed to deep learning systems, to avoid bias and negative social consequences.

Concrete actions needed

The Partnership will:

- **Explore and engage a broad range of stakeholder's perspectives** on the practical dimensions and challenges of finding a **delicate balance** between implementing data-driven technologies and maintaining the necessary levels of protection of human rights and corporate interests, and on the **establishment of ethical conditions for the use of Data and data-driven AI.**
- **Identify strong and robust privacy-preserving techniques** to contribute to the balance between data utility and sharing on the one hand, and data protection compliance and respect for European values and principles on the other.
- **Promote awareness** on prominent data-related fundamental rights issues: **inform citizenship** on the importance of data and the societal and economic benefits of its readiness for use, **raise awareness among business stakeholders (in particular SMEs)** with regards to data value chains, the sharing and re-use of data, as well as the role of **cybersecurity, safety and reliability** in the protection of (fundamental) rights and for addressing data-related challenges.

51 European Commission, "The European Data Strategy," 2020.

52 High-Level Expert Group on Artificial Intelligence, "Policy and Investment Recommendations for Trustworthy AI", 2019, 29; European Commission, "The European Data Strategy," 2020, 3.

- **Provide support in directing research efforts**, focusing on the concepts, the challenges in implementation and the practical aspects of notions such as public interest data, data ethics and the ethics of data sharing, sustainability-by-design and responsible data engineering. The goal should be to identify a **smart mix of technical, legal, ethical and business best practices and solutions**, while also investigating the business opportunities of data sharing beyond their monetisation.
- **Explore and facilitate alternative data-sharing approaches** for end-users and citizens (a.o. data donor schemes and data altruism) to increase the availability of data while respecting fundamental rights and giving control to citizens.
- **Foster the creation of reference datasets, methods and tools** to assess fundamental rights, principles and values (e.g. fairness).

Capturing Value for Business, Society and People

Technical advances in AI and Data are enabling real-world applications. These are leading to improved or new value-added chains being developed and integrated. To capture these new forms of value, AI- and Data-based solutions may require innovative business models that redefine the way stakeholders share investments, risk, know-how, data and consequently, value. This alteration of value flow in existing markets can be disruptive and often requires stakeholders to alter their business models and revenue streams. The Partnership can play an essential role in promoting research and innovation strategies aiming at building value not only for business but also for societal, environmental and individual welfare.

GDPR shapes the European Framework for Data for personal data and the emerging concept of data sovereignty for non-personal data, which requires standardisation and interoperable architectures for data sharing, as a precondition for implementing AI and Data-driven innovation. The challenge is to implement this European Framework without affecting European organisations domestic and international competitiveness and innovation capability with heavy regulation and constraints.

Concrete actions needed

The Partnership will:

- **Multidimensional value approach:** The Partnership can face these challenges by mobilising the industry and research community to focus on building value from AI, Data and Robotics technologies for business, for society, for individuals, with a multidimensional approach. The Partnership should work to align supply and demand perspectives, moving beyond the “pure” business model perspective and supporting the development of the AI, Data and Robotics ecosystem in Europe.
- **Local Innovation ecosystems:** The Partnership could pioneer the use of AI/Data/Robotics in regional innovation ecosystems, providing solutions and support for secure and trusted data sharing and data governance enabling the AI and Data-driven services and tools.
- **Innovative business models with DIH:** The Partnership should leverage its community skills and collective intelligence by collaborating closely with the DIHs to develop and promote innovative business models delivering private and public value through Data and AI.

- **Support the UN SDG:** The Partnership should investigate and promote the potential contribution of AI and Data to social welfare and sustainability, for example as framed by the UN SDG (sustainable development goals) and highlight the value generated by the combination AI/DATA/Robotics in different environments.
- **Public Value Algorithms:** The Partnership could promote cross-sector partnerships around the concept of data-driven public value algorithms that reconcile personal, societal and economic value.

Policy, Regulation, Certification and Standards (PRCS)

It is vital to reinforce and further explore data governance mechanisms to enable data-driven innovation while also endowing European businesses and citizens with 'their' data.[53] In order to allow new and innovative use of data, a balance must be struck with regards to power over data and the need to access data, taking into account the specific situation of SMEs. An experimental research approach is therefore needed to identify the factors for success or failure of different data governance mechanisms, to evaluate horizontal vs sector-specific regulation of data and to promote agile policy-making solutions (e.g. regulatory sandboxing) to balance innovation and regulation.

Standards and certification can be employed as mechanisms to leverage best practices to build trust in AI/Data/Robotics products, services, tools and processes. This important potential needs to be fostered, and challenges regarding, e.g. fragmentation, market uptake and development procedures should be countered.

Increased collaboration between standardisation bodies, regulatory bodies and multi-disciplinary teams of societal and industry stakeholders, including sectorial and citizen participation, should counter the fragmentation of standards. Further attention should be given to find innovative ways to simplify standardisation and certification-related processes and activities. A strategy should be developed to identify the components in need of standardisation, such as interactions and roles within an ecosystem, and to approach PRCS from a life-cycle perspective thereby bridging the gap between research and standardisation.

Concrete actions needed

The Partnership will:

- **Document European and International Standards and Standard Development Organisations relevant to the partnership** (standard observatory).
- **Support standardisation** by promoting the sharing of best practices, increasing collaboration between standardisation bodies, regulatory bodies and multi-disciplinary teams of societal and industry stakeholders and providing input for policy and through **close cooperation with relevant European and international organisations** (including CEN-CENELEC; ETSI, ENISA, OECD, WTO, ITU, ISO/IEC JTC1 SC42, IEEE, etc.).
- Promote the development of **ecosystem standards**, allowing not only actors and products to be certified but also the interactions and roles of different actors within an ecosystem and work towards a **shared taxonomy of the domain** (Data, AI, trust, system engineering).
- Widespread adoption of **international standards and certification mechanisms for data spaces.**

53 European Commission, "The European Data Strategy," 2020.

  - Proactive **engagement with international standards and guidelines bodies** (including data valuation) based on emerging data spaces (in market and projects).
  - Investigate and promote **trust-enabling solutions** (e.g. data rights management as ownership solution) and identify or establish KPIs that drive **standardisation of successful technology, methods, and best practices** (e.g., FAIR principles for non-research data).
- **Assist the creation of next-generation standards** through supporting **consistently emerging standards development** and efforts to find innovative ways to **simplify standardisation and certification-related processes and activities**, and promoting **standard formats, open standards** for data interchange and **guidelines for data and knowledge exchange.**
- **Standards training** through webinars and courses, standards process outreach and dissemination.
- Initiate **alignment of EU legal and governance structures** necessary for the safe, fair and democratic Eur opean-wide data sharing, and **promote development and uptake of auditable norms** (fairness, accountability, transparency), help create a **catalogue of features and requirements** any AI-based system must have and fulfil respectively to be assessed as **transparent and explainable**.

Innovation Ecosystem Enablers

Skills and Knowledge Exchange

The issue of skills related to the growing pervasiveness of Data in business and society is twofold: on the one hand, it is necessary that data experts are capable of putting data to good use, beyond the scientific and technical challenges; on the other hand, non-experts (i.e., the wider society, which is the ultimate target of data-enabled solutions) must be able to make good use of Data and become active players in the data value chain. Awareness and trustworthiness are important topics to address when devising skill development programmes, both for experts and non-experts. A related topic is the provision of mechanisms for exchanging knowledge between the two communities, fostering uptake and further advances in science, technology, and business models, as well as promoting data entrepreneurship.

Challenges

As the reliance of businesses on data grows, so does the need for combining data expertise with domain knowledge and functional skills: data scientists need to understand business needs and how to use data on them, together with understanding data and how they can be used in solving real-world problems. Other skills that are important to further develop are related to governance, ethics and ethical use of data, and best practices, especially concerning privacy compliance.

On the scientific and technical side, besides the obvious skills on mathematics, statistics, algorithms, and specific IT skills and tools, the need for operational skills for data processing will undoubtedly increase as data volumes, reliability, interoperability, and security concerns grow.

Openness (data, software, access to knowledge) stands to be an important piece of the foundations for data skills development, aligned with European values, guaranteeing gender, age, and sector balance, as well as technical, business and societal innovation. There are a set of key stakeholders to this endeavour: academia and research institutions, and the new online learning platforms; large companies, SMEs and start-ups; governments, including regional and local, supporting organisations engaged in data skills development programs to reach citizens and companies.

Concrete actions needed

The Partnership will:

- **Promote vocational education and training** (VET) on data and data-driven systems as an enabler for skilling, reskilling and upskilling, by setting up wide-scale enterprise training programmes, and by including training as a core component of funded projects. Setup Training programs for non-expert users of Data and AI-based systems, who are domain experts and need to know basic Data and AI/ML concepts.
- **Develop data business-orientation** by fostering business skills education (for data specialists), and specific training for SMEs and start-ups to capture value from data, raising awareness of business demand for data-driven solutions.
- **Promote a Euro-wide data science skills strategy**, including a common framework for skills development and certification on data, identifying significant skill-set gaps in the workforce, devise reskilling and upskilling roadmaps, advise education and training bodies with remedial action, match market needs with skills in junior profiles to assess gaps to be addressed in curricular education.
- **Ensure data skills development in alignment with the European Commission** at different levels, like the collaboration with DG EMPL on the European Skills Agenda, the inclusion of data industry needs in ESCO and Europass platforms, and with inputs to support the implementation of the Digital Education Action Plan.

Data for AI

To further develop and meet expectations, AI technology requires large volumes of cross-sectoral, unbiased, high-quality and trustworthy data. The realisation of common **safe, trusted and scalable data sharing spaces** is thus crucial. The main bottlenecks to this vision, as observed through multiple forms of consultation with key stakeholders, are of business, legal and organisational nature. Some of these challenges are addressed in the other sections of this SRIDA (as linked in the footnotes). Here, we focus on transversal actions that seek to raise the trustworthiness, reliability and visibility of data sharing spaces.

Challenges

We distinguish between two categories of concerns: inter-organisational (lack of suitable data sharing ecosystems) and intra-organisational (issues faced by data producers and consumers, as data sharing participants). The top inter-organisational concern remains a lack of functional and trustworthy data sharing ecosystems that inspire large-scale participation, often due to a lack of robust legal and ethical frameworks as well as governance models and trusted intermediaries that guarantee data quality, reliability, and its fair use. Furthermore, emerging best practices and standards are too slow to mature or not widely adhered-to (e.g., interoperability, provenance and quality assurance standards). The rapid shift towards decentralised mixed-mode data sharing and processing architectures also poses significant scalability challenges. Finally, technical data sharing solutions need to better address European concerns like ethics-by-design for democratic AI.

The first of two intra-organisational concerns is the difficulty to determine the value of data, due to a lack of data valuation standards and assessment tools, compounded by the highly subjective and party-dependent nature of data value and the lack of data sharing foresight exhibited by a majority of producers. The second concern sees data producers struggling to balance their data's perceived value against risks exposed by its sharing, even when adhering to standard guidelines: e.g., loss of control over their data (due to the fluid nature of data ownership, which is hard to define legally), loss of trade secrets in a very competitive business landscape due to unintentional exposure or malicious reverse-engineering, legal constraint and data policies breaches (including GDPR and exposure of private identities).

Concrete actions needed

To spearhead the **convergence** of existing national and regional concepts, efforts, priorities and strategies the Partnership seeks to:

- Support the **mapping of existing relevant initiatives** at EU, Member State and regional level, through the alignment of legal and governance structures and efforts around concepts such as sovereignty and privacy, and the collection and systematic analysis of data sharing use-cases.

After an acceptable degree of convergence, the Partnership will support the **deployment** of successful, trusted data sharing framework and governance structures by contributing to the:

- **Development of Rules and Guidelines** to create and design data sharing spaces and evolve the technology (privacy-, interoperability-, security-, quality- and ethics-by-design) and standards, with an emphasis on an **interoperability initiative** to facilitate data and knowledge exchange across existing spaces (cross-sectorial vocabularies) and the **deployment of trustful solutions**.
- **Piloting** towards evolutionary steps of European data sharing spaces that involve all stakeholders, exploiting the available **experimentation instruments to test drive innovative solutions** in safe and dynamic European-wide business scenarios.
- Establishment of **EU-wide Data Governance** to clearly define rules of conduct for the fair use of exchanged data after testing different approaches to assessing the impact of data sovereignty and determining means for **Conformity Assessment** that guarantee trust.

Deployment activities need to be complemented by greater **awareness** of opportunities in an open, fair and ethical data economy. The Partnership seeks to support the promotion of:

- Initiatives targeted at guiding **organisations to revisit their data strategy and lifecycles** to enable the production of data that is sharing-ready by design.
- EU-wide **citizen-oriented** initiatives for an open, democratic and fair data economy and **the right to the free flow of data** that is both safe, secure, and trusted.

Experimentation and Deployment

Experimentation is critical for Data and AI-driven innovation because of the need to deploy in complex physical and digital environments. Furthermore, experimentation plays a crucial role in innovation pipelines, being vital for supporting investment decisions. Data and AI-driven innovations rely on the interplay of different assets, such as Data, Robotics, algorithms and infrastructures. Deployment of testing and experimentation environments, the collaboration between innovation infrastructures, and stimulation of data sharing are some of the most relevant initiatives to ensure availability and proper access to the required assets.

Challenges

There is the need to identify and prioritise challenges that can be better tackled through the potential for transformation and value creation of data, exposing data value chains. This should consider non-traditional innovation models, using data to improve products and services iteratively, rather than just following linear pipelines from research to deployment and uptake, blending open/close innovation models to facilitate experimentation. Interoperability, reproducibility, and data sharing are critical success factors for data innovation and experimentation, as well as experience in-field experimentation and testing on relevant use cases.

Entities such as data-driven DIHs, linking research with industry, environmental, and society needs, play an essential role in this context, enabling federated settings for data sharing, experimentation, and learning. It is necessary that smaller actors like SMEs and start-ups, as well as public entities, be provided with suitable access conditions to experimentation environments (affordability, funding, and as-a-service approaches), both as data consumers and providers.

Concrete actions needed

The Partnership will:

- **Promote data sharing by design**, with win-win models that stimulate organisations into sharing their high-value data. This includes data openness to allow innovative SMEs and start-ups to contribute to the data monetisation landscape, bringing creativity and agile development.
- **Deploy data spaces to hold high-value reference datasets (cross-sectoral, large-scale, close-to-real, annotated)**, and develop industrial benchmarks and test suites, for validating results built on top of those datasets for research and experimentation, following FAIR data principles, ensuring sustainability and long-term persistency, and accessible to stakeholders from large industry, research centres, SMEs, and public administration.
- **Bring together relevant actors in the European AI, Data and Robotics ecosystems**, providing guidance to industry on how to experiment and extract value from their data, and educate on the role of trusted actors, like DIHs, as enablers for experimentation and deployment. Align current instruments for experimentation and deployment (i-Spaces and data-driven DIHs), with those planned in the new Digital Europe Programme.
- **Reinforce links to relevant European stakeholders,** by collaborating with existing innovation infrastructures (e.g. EOSC, NESSI, EuroHPC, AI4EU, GAIA-X, or specialised living labs and CoEs), and engage with major initiatives offering experimentation activities that rely on data sharing (e.g., EDIH, BDVA i-Spaces) to jointly explore new sustainable businesses, cross-sectorial opportunities, and organisational models. In particular, with the integration of assets at different levels: data platforms and marketplaces, services, tools and platforms, finding new testing and experimentation environments for producing, storing and processing data, under common European rules for governing repositories, interfaces, and procedures.
- **Foster the development of new and maintenance of existing infrastructures** to generate, aggregate, mobilise, and leverage data for experimentation.

Technology Enablers

Data Protection and Privacy

Modern AI applications crucially depend on large volumes of real-world data, including data about natural persons. On the one hand, AI-based systems using personal data open up a plethora of new applications. On the other hand, such systems also constitute new attack surfaces, through which malicious or irresponsible parties may threaten people's privacy, or in some cases, even people's security or safety. For example, several types of machine learning models have been shown to be vulnerable to attacks that disclose parts of the training data – which could include information about the location, the habits, or the health condition of individual persons. Therefore, protecting data for AI has become a topic of enormous importance. This calls for improved privacy-preserving technologies to be deployed in all applications involving personal data.

Challenges and expected outcomes

Challenge	*Expected Outcomes*
Data protection in machine learning: protecting the confidentiality and the integrity of training data, learned models, and test samples	Medium-term: Development of **privacy-preserving machine learning techniques** Long-term: Adoption of **post-quantum cryptography** to protect data
Data protection in dynamic environments: (e.g., cloud/fog/edge), resource-constrained devices (e.g., mobile devices), and immutable data stores (e.g., blockchain)	Medium-term: Specific **data protection techniques and tools** for tackling the specific challenges of different technical environments Long-term: Customizable **generic data protection techniques** that can be tailored to the specifics of different technical environments
Explainable data protection: ensuring that data processing is compliant with applicable legislation, making data protection transparent and enforceable	Medium-term: Advances on automated, guaranteed, and **verifiable compliance with data protection regulations** Medium-term: Improved **user control of data** protection measures
Anonymisation and pseudonymisation: protecting the identity of individuals in data sets	Medium-term: Development of **data anonymisation and pseudonymisation techniques** with provable privacy guarantees and limited impact on the utility of the data Medium-term: Digital twinning with **statistical reliability and relevance**, but not linked to specific persons

Sensing and Perception

Sensing and Perception technologies are responsible for collecting all sorts of data and enable their transformation into useful information to support decision-making. It can be earth observation data to support water quality monitoring, blended with social media monitoring to support "robotic journalism," or data collected from heterogeneous sources (e.g., IoT), allowing to extract evidence to support policy development, implementation, and evaluation for smart cities, or to provide real-time environmental data to autonomous, connected vehicles or even unobtrusive monitoring of persons for home healthcare, etc.

In general, this requires large collecting infrastructures to gather the data (*sensing*), as well as large computational resources for data fusion, mining and knowledge extraction, and availability of annotated data for training and fine-tuning deep learning models, building the data assets from which useful information is devised (*perception*).

This technology enabler provides the means to represent physical entities into digital twins. The more data and AI-based modelling and processing available, the more holistic can be the representation of the physical world, and the more accurate and comprehensive are the results enabled by it. Cloud, edge, and fog models and infrastructures, as well as connectivity and security, are very relevant topics in this context. Likewise, heterogeneity of data sources and formats plays a crucial role, as data may be gathered from sensors (physical devices), web resources, data stores, manufacturing machinery, measuring systems, social media or other human input-based sources.

Challenges and expected outcomes

Challenge	***Expected Outcomes***
Trustworthiness: Transparency of algorithms, data processing and management, traceability, privacy, integrity, and accountability	Medium-term: Development of t**rusted execution environments** for edge devices, to keep sensitive data within the source Medium-term: **Large-scale pilots** on data-based solutions, to provide stakeholders with more meaningful and trustworthy results Long-term: Advances in **explainable AI** for increased public confidence
Data Heterogeneity: Formats, collection mechanisms, access methods, flow, and meta-data, as well as coping with diverse environmental conditions (physical, technical, human)	Short-term: **Hybrid data-driven models**, supporting event, discrete and continuous dynamics, taking advantage of foundations like the WoT, NGSI-LD or SAREF, to deploy novel data exchange platforms and smart applications Medium-term: **Coherent standardisation landscape** covering formats, processes, APIs, services and microservices, to foster data sharing, brokerage, and interoperability
Capacity: Connectivity coverage, quality, and capacity for carrying large volumes of data, edge capacity and security to cope with big decentralised data and AI processing, energy consumption by physical sensors	Short-term: **Multimodal data fusion models** for an efficient combination of multi-channel data streams, including synthetic data enrichment, to decrease the complexity of data gathering Short-term: Deployment of **decentralised and decoupled services**, over low latency, low energy systems and networks (e.g., 5G, embedded computing) Medium-term: Deployment of **energy efficiency** solutions, with self-configuring, low-power or energy harvesting capable sensor devices, and low power data transmission Long-term: Development of **novel computing hardware** to efficiently process run novel algorithms to process novel data types

Knowledge and Learning

Data is the source of Knowledge and Learning technologies; data needs to be transformed to become usable. The Knowledge and Learning enabler is strongly related to all other cross-technology enablers from a data perspective: the extraction of knowledge and insights from data obtained from *Sensing and Perception* enables *Reasoning and Decision-Making* and allows between physical and digital worlds. More specifically, data-driven and knowledge-based models allow to a) support the fully automated enactment and actuation of decision, establishing a significantly higher level of automation and reliability of processes, b) develop safe, secure, and reliable AI functionalities and c) create sustainable digital twins along the complete lifecycle (product and production) that provides value to AI data integration.

Today, novel machine learning and data mining methods use computational methods to extract knowledge and insights directly from the data without relying on predetermined expert-defined rules and functions. These algorithms adaptively improve their performance as the amount of data available for learning increases. Furthermore, new types of (distributed) knowledge extraction, new architectural solutions, more sophisticated testing and validation techniques are currently being developed.

Nowadays, the availability of massive datasets is enabling learning systems to surpass previous expectations by becoming more accurate, adaptable and scalable. Nonetheless, the quest for small data learning, continuous learning and transfer learning will remain on the agenda together with the search for efficient architectural design and hyperparameter optimisation. To derive value from data and domain knowledge, methods from both symbolic AI and statistical AI need to be combined to give the maximum potential and usability of data-driven AI-based applications. Additionally, data-driven and knowledge-based approaches must be duly integrated as they result in more accurate knowledge generation.

Challenges and expected outcomes

Challenge	*Expected Outcomes*
Data Quality: Access and processing of **data in a high-quality** and efficient manner: addressing data pre-processing challenges for the various data types	Medium-term: Deployment of **verification systems** and services, for fact-checking and identification of unreliable multimedia content and online misinformation Medium-term: Methods for **identification of risks and liability** for raw and processed mixed data (storage, sharing) Long-term: **Advances in tools and methods** to identify quality issues in the data and algorithms for quality assurance of data, software, hardware, and business processes Long-term: Development of **techniques, standards and guidelines** to detect and mitigate anomalies, concept drift, completeness, representativeness, and bias in data

Extracting meaningful insights and improving knowledge representation from **heterogeneous data**, improving the data assets by addressing data pre-processing challenges for the various data types, **in particular unstructured data**, such as language, images, video, text, sound, etc	Short-term: Methods for annotation of unstructured data sources, **unbiased and representative input data**, methods for handling volumes of real-time data with high velocity, etc Medium-term: Large scale pilots for the generation of enriched and high-quality input data for analytic applications Long-term: Development of methods in **advanced analytics and learning techniques** to derive insights, patterns, events, data anomalies detection, sentiment and emotion analytics, etc. from heterogeneous data sources, and advanced learning techniques Long-term: Development of techniques to **automatically annotate or label data**, integrated into systems with intuitive human-machine interfaces to quickly verify both annotations and labels
Technical challenges directly linked to the **deployment of sectorial and cross-sectorial European Data Spaces and data sharing**	Medium-term: Deployment of frameworks for **data governance**, enabling data collaborations, reference architectures, methods, tools, and platforms for data sharing to enable the development of trusted technologies, products and services while respecting individual rights Medium-term: Increase the availability of **interoperable datasets**, and in general interoperability of data and formats. This also includes the challenges of mixing of personal, non-personal, proprietary, closed and open research data
The Scaling and Federation of Data and AI systems	Medium-term: Development of frameworks for seamlessly combining simple AI-models into large scale federated systems and development of coordinated **initiatives for advancing** data analytics methods with large datasets in flexible environments Long-term: Development of **novel architectures with the capacity of supporting** scenarios based on distributed data storage locations, for data-in-motion and data-in-rest while satisfying the privacy, robustness and performance requirements from the user side
Ethical implications on the use of Data and Data-Driven AI	Medium-term: Coordinated, cross-sectorial **initiatives for establishing ethical conditions on the use of Data and Data-Driven AI** Long-term: Development of tools and mechanisms to **identify bias in the data and algorithms**, risks and liability for raw and processed mixed data (storage, sharing)
Deriving value by combining data insights & domain knowledge	Medium-term: Development of frameworks that can be combined to give the maximum potential and usability of data-driven AI-based applications and launch of **large-scale pilots** on data-based solutions, to provide stakeholders with combined insights Long-term: Advances in **explainable AI** for increased public confidence/design and development of interpretability methods of AI models (explainable AI)

Reasoning and Decision-Making

Decision-making is always necessary for any application domain. Having data available allows us to extract information from data. Nowadays, humankind has enough data, computing power and sophisticated software tools to analyse the available data in any application domain. Hence, making decisions based on information extracted from data becomes mandatory. In this context, AI already plays a crucial role in helping human beings to make decisions thanks to the capacity of AI techniques to **learn from data**. So that, AI-based systems can (i) play the role of a **decision support system** when decisions are made by human beings, (ii) be entities that **make decisions autonomously**, or (iii) be **one more partner in human-machine hybrid decision-making environments**. In any of these three possible scenarios, **trustworthy decision-making requires high-quality data**.

Guaranteeing the use of quality data to create AI-based solutions is not straightforward. Quality data must fulfil the following requirements: (a) unbiased and balanced data, (b) data completeness, (c) data representativeness, (d) properly labelled and/or annotated data, and (e) open data whenever possible without compromising the privacy of individuals or companies. All this leads us towards the four principles of FAIR data: Findable, Accessible, Interoperable and Reusable data.

Challenges and expected outcomes

Challenge	*Expected Outcomes*
Heterogeneous Data: Decision-making with high-velocity data from different sources (edge-fog-cloud), high-variety of data types and formats. Lack of datasets to train decision-making models	Short-term: Innovation actions aimed at developing AI-based systems able to deal with different data types and formats, to **support industry to address distributed decision-making tasks** where it is needed to process **heterogeneous data** in the **computing continuum** (edge/fog/cloud) Short-term: Research and innovation actions to **design new simulators** and improve existing ones in order to **generate large enough datasets** for specific decision-making tasks Medium-term: **Quality standards** to **validate** datasets generated by using **simulators**
Trustworthiness: Transparency, explainability. Lack of testing and validation of AI-based solutions	Short-term: Quality standards for **reference datasets** that will be used to test and validate AI-based solutions Short-term: Research and innovation actions focused on improving AI and Data techniques to work reliably with **insufficient** and **missing** data Medium-term: **Benchmarks** for determining the performance, robustness, reliability, usability, and other quality indicators of AI-based systems
Reasoning: Decision-making with symbolic, sub-symbolic, non-symbolic and heterogeneous knowledge under uncertainty	Medium/Long term: Development of AI techniques **designed** to combine **background knowledge** with **high-dimensional data** and **able** to deal with **symbolic, non-symbolic** and **heterogeneous** data for **semantic reasoning** in future **support decision systems** and **autonomous decision-making systems**

Action and Interaction

Appropriate and safe interaction between the digital and physical worlds is strongly dependent on the availability of large volumes of data such as real-time sensing, stored information, long term knowledge acquisition and multiple modalities and languages. The availability of such data is first and foremost a pre-condition for the establishment of interactions between humans and AI respecting social, physical and environmental context and for the development of *collaborative and distributed intelligence*. Additionally, data is produced in the course of machine-human interaction that should be reintegrated in the data life cycle. For all these reasons, data lies at the heart of this cross-technology enabler and constitutes one of the premises for the development of seamless operation of AI digital and physical technologies.

Today, attention needs to be paid in particular to a) supporting the use of training data to emulate the naturality of human-human interaction, such as in the case of brain-computer interfaces and interaction mediated by VR/AR-interfaces and b) understanding and designing data-driven collaborative problem solving, where humans and machines can take advantage of each other's very different strengths. Additionally, research aimed at addressing some of the critical data challenges for this technology enabler can play a critical role in ensuring societal trust in humans and machine interaction and in developing safety and trustworthiness of these systems.

Challenges and expected outcomes

Challenge	*Expected Outcomes*
Language understanding: Improved natural language understanding, interaction and dialogue covering all European languages and age ranges	Medium-term: Large-scale pilots on **multi-language/multi-modal solutions**, to provide stakeholders with relative datasets and testing scenarios Medium-term: Development of frameworks for advancing **language understanding**
Collaborative intelligence: Human and AI symbiosis	Medium/Long-term: Large-scale pilots on **collaborative intelligence** improving the interaction between humans and AI
Natural interaction methods: Enhanced interaction for humans across the continuum of computing environments	Medium-term: Development of the techniques and methods to achieve **seamless and natural interaction** in unstructured contexts, including multimodal interaction and the development of generic interaction models Long-term: Pilots for the development and testing of longer **continuous meaningful multilingual interactions** (e.g. many hours and more)
Data interaction technologies: combining data-driven methods with Virtual Reality (VR) and Augmented Reality (AR) and their relation to human interaction both digital and physical	Medium/Long-term: **VR and AR** for extended use of these technologies in interactions with large-scale datasets

Safety-critical Interactions: Ensure safe interaction in safety-critical and unstructured environments	Medium/Long-term: The co-development of **technology and regulation to assure safe interaction in safety-critical** and unstructured environments. This includes the development of actuators, mechanisms and data-driven control strategies for safe operation and the launch of large-scale pilots on safe interactions in safety-critical and unstructured environments Long-term: The development of data-based **confidence measures for interaction and the interpretation of actions** leading to explanations of interaction decisions and improved decision-making and the establishment of guidelines and templates to design intuitive human-machine interfaces

Systems, Methodologies, Hardware, and Tools

Spreading the use of AI-based solutions demands much more **powerful** and **complex computing infrastructures** for storing and processing vast amounts of data. Processing mainly refers to training & validating ML models designed to **learn from data** that are at the core of the AI-based solutions. **HPC, Cloud, and Edge** are **key** enabling **technologies** that provide the foundations on which to build **hybrid, modular, versatile and virtually-unlimited horizontally-scalable** architectures. Deploying AI and Data systems often requires the integration of diverse technologies ranging from software to hardware. Ensuring trustworthiness requirements, such as reliability, privacy, robustness, safety, dependability, transparency, etc. requires data-driven methodologies and tools as well as data-based validation processes and means for verification.

Managing data-intensive architectures is challenging and requires (a) to encompass all aspects of data in relation to physical systems; (b) **best practice guidelines** for design, implementation and deployment; (c) **foster interoperability** and **standardization** practices concerning data, algorithms, software frameworks and platforms to make the architectures really **hybrid** and **collaborative**; (d) native **integration** of **data-driven** and **knowledge-based** approaches and their deployment on hybrid systems; (e) deployment of **orchestration technologies** to make it **easy, transparent** and **flexible** the use of **hardware resources**; (f) use of monitoring and measuring tools for **failure prediction** and **detection** — data can help to identify hardware and software anomalies; (g) **software abstractions and "by-design" approaches** for data processing pipelines; (h) compiler technologies for **heterogeneous hardware** targets; (i) domain-specific **programmable hardware** (e.g. based on FPGAs or open hardware); and (j) programmable network devices that can support monitoring and operations of the network connections in a distributed system.

All this in order to (1) **facilitate the access** to next-generation data and computing infrastructures, (2) **offer** them as **shared** and **common** computing facilities, (3) give support for the **integration** and **deployment** of **heterogeneous data-intensive intelligent** systems developed by different stakeholders but able to cooperate, and (4) create a common and affordable **European data space** that can support stakeholders on innovative research and AI-based services deployment.

Challenges and Outcomes

Challenge	Expected Outcomes
Scalability: lack of an ecosystem to guarantee access to computing infrastructures across Europe	Short-term: Resource managers designed to **dynamically allocate computing resources** and **adapt themselves to evolving workloads** to cope with the heterogeneity of AI workloads by redistributing computation tasks at runtime Medium-term: in order to **efficiently exploit** next-generation computing infrastructures and **hybrid configurations** with resources in the **computing continuum** (HPC/cloud/fog/edge, including embedded systems), as well as to facilitate **real-time processing** of data streams Long-term: **HW accelerator-based architectures** (GPU, FPGA and new processors) ready to converge with classical CPU-based HPC, Cloud server, and Edge architectures by **including** GPUs or other HW accelerators in **all compute nodes**, and designed to run **data-intensive** computation workloads
Methodologies design, implementation, and operation of data-processing hardware-agnostic pipelines	Short-term: Software **abstractions and "by-design"** approaches for implementing data-processing hardware-agnostic **data and AI pipelines** Short-term: Advanced compiler technologies targeting both **specialised hardware** accelerators and **programmable hardware**, in order to set up **domain-specific platforms** for **fast data processing** Medium-term: New models to efficiently distribute computation workloads, able to leverage **hybrid configurations** with resources in the computing continuum (**cloud/fog/edge**, including **embedded** systems) Medium-term: Methods and metrics to **evaluate** both the **performance** of **AI systems** and the s**oftware development process** followed to manage, develop and deploy such systems Medium-term: Use of data to **design more efficient** hardware
Reliability Ensuring robust, safe, reliable, and trustworthy operation of AI systems	Short-term: Use of data to **identify hardware** and **software anomalies** as well as **improve** the **design** of **new systems** able to **adapt** the **use** of **resources** to the **demand** of computation power, e.g. tuning the speed of microprocessors or start/stop containers Short-Medium-term: **Quality standards and methodologies** to verify and "by-design" approaches to improve the **reliability** and the **robustness** of computing infrastructures to detect internal/external attacks that could compromise the **security** of data sets and AI software applications
Deployment: Deploying modern AI applications in the computing continuum (embedded-edge—fog—cloud) and the transition from development to production environments	Short-term: Tools to design the **development** and **deployment** of AI applications/systems whose **software components** will be **deployed** in the **computing continuum** (edge/fog/cloud) and embedded systems Medium-term: Frameworks and guidelines with best practices to **simplify/ automate** the **transition** from **development (proof of concept)** to **production** environments in order to deal with the **heterogeneity** of HW and SW solutions and **reduce** the **time** of **deployment** to **minimise** the **risk** of early **obsolescence**

ROBOTICS DEEP DIVE

Introduction to Robotics

Robots are unique because they create value by performing physical tasks that people cannot, should not, or will not do. Their economic power lies in their ability to intelligently and autonomously move, shape and assess the physical world. Much of the expected value attributed to AI comes from the interaction robots have with people and objects: Robots are an essential part of the "Smart Revolution".

Successfully deploying robots is dependent on acceptance, which in turn is based on trust and understanding. It is therefore essential that technical integration embodies the key qualities of safety, dependability, and trustworthiness; qualities that must be designed into every robotic system. This is an end-to-end endeavour requiring a joint approach that considers, in context, both human and machine and the interaction between them.

Integrating AI technologies is critical to how robots perceive, assess, and interact with people, operating environments and each other. However, this physical intelligence does not simply arise from sensing and computation, it arises from the nature and physical quality of the interactions robot controllers and mechanics have with the world. Robots have become the embodiment of integration science, the way a robot behaves results from the advanced physical and digital integration of its composing technologies.

Relationship between AI, Data and Robotics from the Perspective of Robotics

The unique values provided by robotics come from this composition of technologies and the embedded integration of AI. The need to develop physically embodied systems able to interact with unknown and unstructured environments makes robotics intrinsically complex and different. As a result, the path taken by robotics to achieve exacting physical specifications (speed, dexterity, graceful behaviour etc.) results in differences in the innovation path. This can be highlighted under the following headings:

- **Extended time to market:** The development of hardware and the need to build multiple physical prototypes significantly lengthens the time from lab bench to market.
- **Greater Investment needed:** As a consequence of the longer time to market but more significantly of the greater cost at each development stage requires far greater investment to reach the market place. This is particularly the case at TRL 7-9 where there is a need to build advanced, robust prototypes, to set up manufacturing and to build test and deployment support systems for robots. In addition, the marginal cost of producing additional units is considerably higher than for digital goods.
- **Physical and regulatory infrastructure:** Robotics applications rarely operate as stand-alone devices; they often require infrastructure embedded within operating environments (sensing, communication networks, power etc.) to support both innovation and deployment. In addition, many uses of robotics require new or altered regulatory infrastructure and associated validation and certification processes.

- **Testing zones:** Before entering the market, robots need to be tested in realistic operating environments to minimise potential harm to users and the operating environment itself. These testing zones are needed for each application involving close collaboration with people especially where there are ethical or safety critical requirements.
- **On-platform decision making:** Robotics frequently operates in unstructured and open environments and in everyday environments in collaboration with people. This requires in-time decision making, often with a safety critical or ethical component. Such fast reactivity to events can only be processed "at the edge.", partly based on incomplete and uncertain knowledge. While cloud-based data has its place in higher level mission control on platform, local decision making is an essential part of robotics. Indeed, some operating environments, such as under-sea, cannot provide high bandwidth communications and require local high-quality decisions.

In addition to these factors, there are areas of technical focus critical to Robotics. These impact on the approach taken to technical development and more critically on validation and acceptance:

- **Physical Interaction:** Robots have to work within the constraints of the physics and physiology of the environment and its users and operators. Physical human factors, including reaction time, user comprehension, behaviour and communication time place real and unavoidable constraints on the development of robotics applications.
- **Physical and Psychological Safety:** The trend towards the use of robotics operating in close proximity to humans and for robotics to be used as interactive tools creates a strong requirement for the operation to be physically and psychologically safe. This safety is especially relevant when the power and speed of the robot could cause significant harm to humans and to the environment in unexpected ways, including emotional harm.
- **Actuated-Mechanical Structures:** Robotics is constrained by its essential reliance on actuated mechanical structures and physical interactions. These require tight integration between physical sensing (position, torque, angle etc), controllers and actuators, and in certain applications cloud services. It is becoming increasingly necessary for these mechatronics devices to be "smart" in order to react to changes in the operating environment and also to improve response in compliant and reactive mechanical structures as well as dynamic physical or biophysical interactions.
- **Unpredictable and Unknown Environments:** All of the above factors need to be taken into account and combined with unpredictable and unknown environments, as is the case in many service applications, particularly where this is accompanied by significant constraints on, for example, data connectivity, power, or the ability of humans to intervene, as well as in harsh environments (explosive, radioactive, hot etc.). When doing so, the added complexity of robotics over (pure) AI and Data applications becomes obvious. It is no coincidence that the AI community most often considers robotics as a major source of deep challenges for AI technologies.
- **Irreversible actions:** Algorithms can learn very complex behavioural skills, but the application of such methods in the physical world involves much training, learning, and experience from a robot. Bad policies bring the system to an unrecoverable state from which learning is no longer possible. After each attempt, the environment needs

to be reset to start the process again and improve. However, not all the tasks are easily or automatically reversible in physical environments. For instance, if a robot falls down the stairs, or a surgical robot drills a hole at a wrong position these actions will often be irreversible.

The dependability requirements in robotics are stringent. Lack of dependability can result in real mission failure or real harm that cannot simply be addressed with a reboot or the tweaking of parameters. In critical robotics applications there is often no second chance.

One of the primary benefits of robotics is that they have the potential to be able to overcome these limitations. By doing so, they can become extremely useful tools that can be deployed to achieve tasks and missions that are currently dangerous or impossible.

Robotics integrates a very broad range of technologies to address applications, indeed no other engineering sciences can be considered as multidisciplinary as robotics: the real science of integration. The precise array of technologies depends on the application. Integration solutions also have to ensure safe, dependable and predictable operation, often in circumstances where there is limited or no accessibility to the system. Often, there are also resource and communication constraints.

Synergies with AI and Data

There are three primary areas of synergy with AI and Data. Firstly that robots are significant producers of data, secondly that they rely on data and in some cases external knowledge while operating. The third and most important aspect is that they rely on AI technologies to achieve core functions such as perception, decision making and interaction. Robots need AI and Data to achieve their operational objectives. Furthermore, specific learning paradigms can only be studied, understood and applied in robotics. These paradigms have to do with learning variable compliance interaction tasks that humans do effortlessly every day.

Robotics benefits big data by acting as a significant data source for data analytics and learning systems. In this respect robots add value as they are able to direct their attention to collect relevant data by carrying out onboard analysis and focusing data capture where it may have the most relevance, for example in the inspection of cracks in industrial chimneys. As robots become more prevalent, the information gathering opportunity they present will become significant, especially where they are connected to the Cloud (e.g. via 5G). For example, it is estimated that a typical autonomous car generates some 25Gb of raw data per hour. Therefore, communicating data on a higher abstraction level can also be used as many systems are capable of on-board perception processing and scene analysis. A wide range of data driven business models become possible when robots are seen as value creators.

Besides these technical synergies with AI and Data, Robotics also shares concerns around privacy, cyber-security, modularity and data standards as well as other legal and ethical issues. This includes responsibility, autonomy, diversity, inclusivity, access, and dignity, particularly in application areas that. address human wellbeing or direct physical assistance.

Market Description Aligned to Robotics

Market Understanding

Robotics has been used in manufacturing for many decades providing significant economic advantage. In the last decade, robotics has developed to the point where robots are used routinely at home (vacuum cleaning, lawn mowing), in warehousing, in healthcare, in education and research, in farming and in the inspection and maintenance of infrastructures. These represent the second wave of robotics applications based around service delivery. Understanding, both technical and commercial, around the use of robotics in these markets is expanding. The economic benefit of robotics is being explored and new business models developed. It is now important to consider the broadening of deployment to other sectors, as well as the deepening of existing applications to provide increased functionality. In addition, the use of robotics to benefit society at large also needs greater emphasis; for example in helping meet environmental targets (through exploration and data collection as well as green manufacturing) or address societal challenges (particularly in healthcare and transport). Critical to this third expansion wave are the identification of tractable domain challenges, the development of viable business models, and the promotion of acceptance and understanding in the market.

Market Prioritisation Overview

Robotics has demonstrated its operational utility in many fields where tasks are repetitive, dangerous and tedious. It also has utility where actions require precision, dexterity, adaptation and close human interaction. Many challenges remain to be met: better, safer collaboration between humans and robots, greater autonomy, increased cybersecurity and more robust regulatory frameworks amongst many others.

In robotics, form follows function. The shape and construction of each robot is typically designed for a specific task or mission. Design must focus on the physical requirements and integrate generic technologies into systems that are capable of performing the necessary tasks. Each sector has specific specialisations and regulatory requirements, which also shape the physical and digital form of each robot, especially when these are safety critical. These factors mean that robot supply chains are horizontally generic and vertically specialist. Both is needed for widespread deployment.

The Robotics community, through Horizon 2020, has already identified and supported four vertical key application areas with specific focus:

- **Healthcare** where robotics can impact in multiple areas across the spectrum of healthcare and support services. Robotics in used in intervention, diagnostics, patient care and in rehabilitation as well as in hospital support services. Robotics can improve patient’s recovery time after surgery, deliver improved diagnostics and intervention, help rehabilitation, and enhance hospital services such as sample testing, logistics, and patient transport. The current pandemic has highlighted new areas of application in infection control and in support for social distancing both inside and outside of healthcare settings.
- **Maintenance and Inspection of infrastructure** in both everyday domestic and work environments and industrial environments. Inspection and maintenance is key to maintaining aging infrastructure and to keep people safe; ensuring the water supply,

sanitation and public health; oil, gas and mineral extraction and processing; energy generation and distribution (electric, hydro, wind, solar, nuclear); transportation infrastructure (hubs, road, rail, etc.), in cities and including maritime and off-shore infrastructure.

- **Agri-Food**[54] where robotics impacts in every process from the farmers' field or greenhouse through crop monitoring, spraying, harvesting, sorting, processing and packaging products to their delivery on supermarket shelves. A high degree of automation in Agri-Food will not only foster competitiveness but will be of central importance for ecological agriculture, by reducing the necessity to use artificial fertilizer and biocide, both by the use of physical cultivation technology and by tailoring their application.
- **Agile Production** Firstly this enables greater flexibility in manufacturing, allowing diverse production and customisation ("lot size one") using common robot-based machinery. Secondly, the increased use of agile robotics allows production to return to Europe since it has, in some sectors, the possibility overcome the low wage advantage of outsourcing production even to the extent that with dexterous machines and soft materials handling industries such as textiles and shoemaking might be cost effectively re-shored. For other industries, enabling shorter logistics chains increases resilience.

In addition to these four vertical domains it is possible to identify other areas worthy of attention, notably transport, home and entertainment, construction, logistics, space and energy supply where there are significant market opportunities for robotics. For example, robotics can facilitate in "last kilometre" delivery, by improving road utilisation and in improving material and energy efficiencies for the circular economy, in building construction and decommissioning. There are even niche commercial opportunities in applications such as space satellite repair and debris collection.

While it is possible for these markets to be developed based on the direct economic advantage offered by robotics, there are other applications of robotics that have a broader societal and environmental benefit, where investment, particularly public investment, is critical. Notably in support of the circular economy, for example through automated electric car battery recycling and manufacturing and in contributing to land and marine waste collection and treatment; by improving off-shore renewable infrastructure through automated maintenance. Robots also have a role to play in monitoring the oceans to support climate science and in assessing environmental compliance, for example in waterways, and industrial processes.

Robots are uniquely able to operate in extreme and harsh environments where humans cannot, should not, or will not go; for instance, in nuclear decommissioning tasks, in disaster recovery, in the exploration of space and in helping medical staff cope with emergencies through automated human sample talking, disinfection and contamination assessment. All areas where robotics has been explored in the current coronavirus pandemic.

54 The term Agri-Food is intended to cover a wide range of food production sectors including livestock farming, fisheries, horticulture etc as well as produce processing, ingredient preparation and food manufacture and assembly.

Framework & Enablers

AI, Data and Robotics Framework

European Fundamental Right, Principles and Values

Many of the challenges that AI presents to Fundamental Rights also apply to robotics. In this regard particular attention should be paid to how these principles translate in concrete embodied applications. It is therefore critical that any legal framework put in place to address issues take into consideration the fact that robotics, as set out above, is both developmentally and technically different from AI and Data technologies. Specifically, it has embodiments that differ from application to application and in their use context, often with no human operator accompanying the machine, and with the possibility to directly affect the physical environment. In addition, robotics has to address the allocation of liability for physical actions as well as data subject rights, including transparency issues, around data captured or held by a robot, for example personal medical data.

Other aspects such as diversity and inclusivity, which are crucial for the European Union, need to be fully realised in the robotics sphere. It is essential to empower an inclusive community by addressing gender and diversity issues. Particular attention should be drawn to the dangers of replication and exacerbation of human biases through robotics, e.g., gender stereotyping, racial and gender bias.

Value-Driven AI, Data and Robotics for Business, Society and People

In order to enhance the value derived from robotics it is critical to advance understanding within the key areas and widening the reach of robotics into a next wave of applications. This requires a wide range of deployment support to be addressed; assessment of economic viability and value generation, technical showcasing to enhance understanding of impact, end user community creation, and sector specific innovation support.

In addition to developing the eco-systems around potential application areas and developing core technologies, there is increased awareness that better citizen engagement is needed in order to ensure that acceptance and trustworthiness are properly understood.

Policy, Regulation, Certification and Standards (PRCS)

To ensure the protection of user's fundamental rights, apportion adequate accountability for robot developers, and make sure there is a common baseline of fundamental safeguards, there is the need to create policies, guidelines, and regulations that properly frame the development of robotics. The current legal framework is mostly outdated and does not fully capture the field of robotics, leaving developers and manufacturers with little guidance on how to comply with the law. Moreover, to create a greater market for robotics, it is essential that a legally well-founded supply chain is created both within each key application area and with respect to the delivery of robotic systems themselves. The creation of supply chains is pivotal on modularity and IP encapsulation so that value is gained from innovation. Similarly, trust in the marketplace is dependent on product performance validation and certification coupled to flexible regulatory frameworks that are protective without limiting innovation unnecessarily.

In developing good PRCS around Robotics the following aspects are critical:

- Update and harmonize regulations, with priority placed on sector-specific policies.
- Provide guidance from the regulatory side on how to comply with existing frameworks, and address barriers / enablers to the market.
- Standardisation and certification for upcoming markets.
- The development of test centres and associated testing regimes.
- Interoperability through standardised system modularity and interfaces are needed to enable the fast deployment robot solutions and to reduce integration and deployment costs while ensuring appropriate liability for the system and its components.
- Fulfilment of standardised cybersecurity requirements.
- Scalability of standards to account for different demands in applications, e.g. low/high risk applications or safety requirements depending on size/velocity/force of robots.

Innovation Enablers

Skills and Knowledge

Because of the broad range of technologies integrated within robotic systems, the skill mix needed for success is broader than that for AI or Data alone. While good design will enable users with lower level skills to operate and configure robots, they will still require specific training. There is also a need to teach awareness of robotics and the issues that physical and psychological interaction raises.

This makes the skill shortage in robotics acute at all levels of education, as domains that newly incorporate robotics, such as healthcare, will have to introduce basic training on robotics where workers have to interact and use them. The skill shortages amongst educators limit the rate at which skills can be generated, while on-line learning and the development of interactive training can address accelerated skill acquisition. However, the hard physical nature of robotics means that it is impossible to acquire a complete spectrum of skills without practical training.

There is an important evolution in professional training best illustrated by the impact of new technologies, including robotics, in healthcare. Previously health care professionals were trained to achieve competence (such as. basic device/surgical skills training), whereas now they are more required to train to achieve proficiency. In some areas of healthcare achieving proficiency will need to include training on the fundamentals of AI, robotics and data, which in turn requires that appropriate proficiency standards are defined (e.g. certifications). This also impacts on continuous learning and up-skilling to make best use of new technologies such as surgical robotics available to clinicians.

In addition to professional training, educational access to robotics is needed throughout school education, as well as a robust training on responsible innovation. An early introduction to the field at school level – perhaps guided by university institutions - reduces reservation about the technology and promotes skill development. Robotics provides a simple and motivating hands-on introduction to advanced system concepts such as autonomy, control, sensing and programming which could benefit society in the future, and acts as perfect example to raise the interest of the young towards science and technology.

One way to promote the popularity of robotics technology is to provide low-threshold access to hardware modules and software modules. This together with the availability of robotics development frameworks represents a low barrier to create and use robots up to the semi-professional level. The ability to safely access robotic hardware for training in realistic environments is therefore critical to skill acquisition. Living Labs can offer such access to robots in real environments for the broader community and for researchers dealing with robotics competitions, such as the European Robotics League, which can be an appropriate mechanism for (early stage) skill acquisition.

To increase deployment, there is a need to ensure that decision makers within organisations understand robotics and how it can be deployed. Here greater levels of appropriately framed knowledge exchange, including the one at the policy level, are needed. This also requires greater access to demonstrators and showcases, which need to be focused around end users, sectors and use cases. This is particularly important for new sectors where the economic case needs to be made for long term investment and for the development of new business models and robotic platforms. Complementary to this, Entrepreneurship is also critical to increased deployment. Education of entrepreneurship skill-sets and awareness of opportunities need to be increased both within the robotics community and also within institutions educating the next generation of potential roboticists.

Data for AI

As discussed above robots are both producers and consumers of data; data generated locally from on-board sensor processing and through interaction with cloud-based data resources. Robotics also relies on physical model-based approaches and on the generation of data driven models. In particular, "digital twins" of whole robot systems when coupled to "digital twins" of processes and operating environments allow deep experimentation and system design validation before physical construction. This approach to the integration of complex robotics is at the core of Industry 4.0 and at an early stage of exploration in other sectors, notably: construction, healthcare, energy and the petrochemical industries.

The mobile nature of robot platforms means that the relationship between robotics and data is also dependent on communications. Developments such as 5G, IoT, smart cities and fully instrumented transport systems all impact on the design of robotics and the balance between on-board and off-board data collection and processing. For example, autonomous vehicles on a road with access to reliable low latency high bandwidth peer to peer networks can exchange sensor data and information to make real time decisions as a dynamic collective. Similarly, robots that can interact with smart sensing in cities or homes can extend their knowledge of the operating environment by drawing on external data sources.

Global communications can allow cloud based robotics to acquire new knowledge, for example to recognise an unknown object or gain knowledge about how to handle it. Key data technologies for robotics include hard real-time data processing, low latency decision making, HPC and edge computing, data consistency and standards.

Experimentation and Deployment

For some years now, the European Commission and Member States have been supporting the setting up of instruments such as Competence Centres, Digital Innovation Hubs (DIH), digital platforms and now European DIHs (EDIHs) with the aim of creating bridges between industry and research. Since their creation and their first incarnations, these instruments have demonstrated their effectiveness in establishing a dialogue between industry and research, reducing fragmentation, enabling innovation and facilitating the uptake of robotics by industry. They have also helped spread the sharing of good practices on the issue of robotics innovation in Europe. The existing efforts will continue to add value beyond current funding while new initiatives need to continue to build co-operation between industry and research, to promote new technologies and to give research organisations and supplier companies the opportunity to develop and explore the use of technologies and services to economic, societal and environmental advantage.

Due to the intrinsic nature of robots that interact with the environment, it is also necessary to establish testing spaces and infrastructure that facilitate the validation of new robotics technologies in realistic physical environments that are suitable for testing. Living Labs are needed in order to engage citizens unfamiliar with robots, demonstrate to potential end-users and test robots in real or realistic environments. Living Labs are also needed to test and develop at scale new regulatory frameworks, such as the new European Regulation for the operation of unmanned aircraft.

The further development of DIHs is needed to continue and enhance their role in connecting and collecting different innovation stakeholders, addressing the needs of SMEs and assisting in the translation of technology across Europe.

Robotics and Covid-19

The Covid-19 pandemic has - like previous examples such as the Fukushima accident in 2011 - shown the crucial importance of workable robotics and AI solutions. Unfortunately, it has also demonstrated the gaps in robotics and AI research achievements. While a flurry of robotic and AI systems and appliances have been proposed for substituting humans in dangerous tasks and environments, their actual usage and contribution have been limited.

There are multiple factors that contribute to this. While there are many Use Cases for robotics few have been fully developed to the point of deployment and a crisis is not necessarily the best time to deploy new technology. However new opportunities and greater awareness have resulted from the pandemic that will stimulate uptake in the future, particularly in healthcare applications.

It is necessary to gather researchers in academia and industry to share the ideas so far developed. They need to discuss the challenges still preventing the development of more effective applications of intelligent robots and determine concrete actions.

Technology Enablers

Introduction: Robotics Technologies and AI

Robotics develops its own unique technologies, and in doing so exploits and develops AI and Data technologies. Today, most often AI and Data technologies are embedded within robotic systems in order to enhance autonomous operation in both quality and duration. Embedding AI improves cognitive functions such as perception, decision making and interaction that are the essential ingredients of autonomy. To include AI technologies, they need to be encapsulated and modularised so that functional limits and operational boundaries are meeting acceptance criteria for trustworthy operation. By embedding AI technology into robot systems there are expectations surrounding its impact on operation and performance:

- Simplification of the semantic[55] interaction between people and robots and between robots and their operating environment by adding reasoning and knowledge to transparent decision making.
- AI that is naturally interpretable and decision making based on AI technologies is explainable.
- Actions, interaction and decision making become naturally intelligible to human operators in context of the user's skills background and working environment while taking into account privacy and data security issues.
- AI that enables the building of effective internal models that allow broader and deeper decisional autonomy. This allows for longer interactions in more complex operating environments.
- Prediction of human behaviour in order to offer tools that help an operator to guide a vehicle, or a robot.
- AI that does not negatively impact on the safety (digital and physical) of people who are using robots or who are simply in the vicinity of them or of infrastructure installations while it provides an (economic) advantage through improved operation.

Sensing and Perception

Overview

For robotics the technologies that deliver sensing and perception are fundamental. Without sensing and perception, robots cannot react to a changing environment. At the most basic level, the sensing of joint positions in a robot arm makes a controlled motion possible. At its most advanced level, it allows a robot to understand its environment sufficiently to autonomously achieve complex sophisticated tasks involving objects, people and other robots. More durable interactions in collaboration with people can be sustained by improved perception of human intent, based on appropriate sensors and models of human behaviour.

Dependencies

Sensing depends on sensors, the development of which, for the most part, lies outside

55 We indicate here semantic interaction all what is NOT physical interaction which requires development of physical embodied intelligence in the mechatronics design of a robot.

of robotics. While many sensors are now readily available as commodities, they are developed, and therefore optimised, for other markets so the development of novel and specific sensing for robotics requires support and investment. There are links to both materials, semi-conductors and fundamental physics, where new materials like Graphene and new physics such as quantum may enable step changes in robotics sensing.

Perception of the environment is the key to the safe operation of robots. Traditionally, dedicated safety sensors are used to detect operators, and humans passing by or being in the surrounding of robots. These systems initiate a stop of dangerous movements and actions, if these may result in a risk for humans.

While these safety devices are highly reliable, their functional capabilities are limited to simple perception tasks and limiting the efficiency of robots. Human-robot collaboration will require high-level decision making to be part of the safety-concept for robots, e.g. by predicting the movement of a human in a direct interaction. Safety will no longer solely be accomplished by a dedicated layer but will rely on various types of sensors for perception, high level algorithms for the interpretation of the sensor data and trustworthy decision making to act accordingly. Distributing the safety to different layers will make robots more flexible and reactive while maintaining an acceptable level of risk.

Perception depends on AI technologies, and given that perception often needs to take place on-platform, there is strong dependency on edge-based computation and close integration between sensing and processing. Where communication is limited, robot platforms will need to have the capability to execute all computation, including complex and expensive AI algorithms, in order to operate autonomously.

Challenges

- Real-time interpretation of sensor data particularly in complex environments or where multi-modal data (vision, touch, acoustic, chemical etc) must be fused or correlated to increase self-awareness of robotic systems.
- Matching local point of view with world views particularly in dynamic scenarios.
- Reliability of sensing in harsh environments (pressure, high or low temperature, radioactivity, corrosive atmospheres, explosive risk) and in diverse environments (ice, snow, rain, mist, fog, etc.), as well as in small scale environments (e.g. inside biological bodies).
- Micro scale detection of small objects such as nano particles, and differentiation of chemical compounds, contaminants, and biological tissue (e.g. cancerous cells vs healthy cells).
- Full 3D perception systems and sensors able to decompose and interpret whole scenes in real-time to 4D.
- Fusion of machine learning and model-based approaches to ensure generality robustness, and accuracy.
- Identifying the optimal balance between different sensing methodologies in given application and use cases.
- Social interpretation & understanding of human intention and robot interaction particularly in everyday environments.
- Assurance of the safe operation of robots using data from safety-rated and

standardised sensing devices.

- Monitoring of human bio-signals during robot interaction in order to prevent fatigue, stress, discomfort, etc.

Impact/Outcome

Successful technical developments will enable robot systems to sense and interpret their operating environment, which may include humans, accurately, quickly and in context, enabling them to fulfil their tasks more efficient and safer. Assuring the safe and efficient operation of the robots will furthermore reduce the incentives to manipulate safeguarding devices, e.g. in manufacturing processes.

This needs to be achieved at low power and high speed and using on-board processing. Integrating high level information into low level controllers will enable greater reactivity to dynamic environments. Embedding advanced sensing into mechanical structures can dramatically improve responsiveness and interaction quality.

Data, Knowledge and Learning

Overview

With respect to Data, Knowledge and Learning robotics leans heavily on AI and Data technologies to provide the needed capabilities. However, the raw technologies produced by AI and Data researchers need to be shaped against the fundamental characteristics of robotics and the needs of applications that interact physically. Robotics is both a producer and consumer of data, while much of this is produced and consumed locally (i.e. on the robot platform) much of it also has value off-platform. Here, privacy concerns and GDPR[56], including any future GDPR type AI regulation, play a major part shaping both the "what" and the "how" for the use of data gathered in robotics. This in turn impacts on trustworthiness and on function, setting challenges for all business leaders, entrepreneurs, and system developers. For example, an autonomous car has the potential to capture data about people outside of the vehicle, what they are doing, or carrying or if they are entering shops etc. If data from multiple vehicles can be joined then highly valuable knowledge can be generated. Clear guidance is needed on where the limits on such knowledge extraction and learning become unethical or breach privacy laws.

Many applications are not subject to such issues and the ability of robotics to capture, process and communicate data, and knowledge derived from it, is critical to both the function of robotics and to wider data analysis, for example in warehouses or on farms. Robotics also consumes data in order to carry out complex tasks for example in warehouses data concerning the physical location of items, their shape, size and ,weight, etc is valuable in being able to plan motion and grasping actions. The need for data availability will have to be juxtaposed to data accuracy and data minimization principles, among others, demanding privacy regulators provide more clarity in such regard.

While there is a general need to converge on hybrid approaches to learning by merging the advantages of deep learning with classical AI techniques, there are also specific issues with robots and learning. Robots need to learn from experience and from each other in order to improve and become more efficient. However, in many cases, the number of available examples is limited. Highly efficient learning mechanisms are therefore required

56 General Data Protection Regulation

that can learn quickly from very small data sets. Often a robot will have to guide its own learning actions (based on its current mission and knowledge) if it is to be effective and safe. This learning from sparse data also has to be achieved in near real-time. To support trustworthiness, such learning should provide reliable explanation as to how the learning goal was achieved, sufficient to assist the assurance of safe operation. Learning can also present issues in safety-critical applications where certification is a prerequisite to deployment. However, if the robot learns as it operates, static certification processes may no longer reflect the evolved version of the robot. Here, efficient means of online monitoring and possibly run-time certification need to be established.

Dependencies

Data acquisition depends on sensing and perception to deliver sufficiently high-quality data for processing. Knowledge extraction depends on models and on categorisation technologies.

Challenges

- Creation of an innovation ecosystem that allows robots to use external data systems to increase quality and coverage in large scale data rich applications.
- Standardise information / knowledge / action sharing mechanisms among robots in applications where multiple robotic systems are required and standardised across Europe, including anonymisation mechanisms where appropriate.
- Integrating robots into IoT and Smart City ecosystems, industrial asset management systems and digital twins, so that data and knowledge can be shared.
- Maintaining privacy and operation within relevant legal frameworks with respect to privacy and trust.
- Creation of hybrid AI systems, merging powerful deep learning techniques with reasoning / knowledge-driven approaches.
- Learning from sparse data in near real-time.
- Creating transparent interfaces such that AI results are explained and users are able to evaluate the validity and integrity of the results.
- Creation and refinement of models through learning that enhance decision making.
- Integrate safety assurance of self-learning components into safety-critical systems, both at design and opening them for the required verification activities and certification processes at run-time.

Impact/Outcome

Enhancing robotics with enhanced data, knowledge and learning capabilities improves adaptation to new and novel operating conditions. Improved access to big data and knowledge will enable robotics to integrate more effectively into complex operating environments such as factories, warehouses and hospitals. Learning, especially learning from sparse data or by observation, will create more flexible and adaptive systems able to learn by example. The safety of these adaptive systems will be enabled by appropriate methods at design-time and at run-time.

Reasoning and Decision Making

Overview

Reasoning and making decisions about the physical world carries with it constraints, such as physical human factors or aligning with human intuition. The need for traceable and reliable decision making is also critical in any safety critical applications.

Dependencies

Reasoning and Decision Making technologies depend on sensing and perception technologies and on interpretation and knowledge driven by AI. Safety assurance is critically dependent on these technologies.

Challenges

- To deliver explanations of reasoning and decision making processes that are human understandable and which allow humans to validate decisions where necessary.
- Ensuring trustworthy decision making that includes human factors and human context, especially in safety critical applications.
- Safety assurance of high-level decision making.
- Planning and replanning, and decision making under uncertainty and incomplete knowledge in dynamic environments. Time, communication and computational constraints typically apply here as well. This challenge is amplified in multi-actor environments requiring collaborative action.
- The development of adaptive decision making that avoids over-tailored solutions and seeks to balance performance optimisation with adaptability.
- Distributed decision making and coordinated decision making between robots and in combination with other external systems including humans.
- Consistency and linkage both within and between the abstraction layers from robot components and skills to models used for reasoning, decision making, and explanation (upwards and downwards) including grounding in the real world.

Impact/Outcome

Improved reasoning and decision making, able to deal with uncertainty or incomplete knowledge, expand the operating envelope of robot systems and allow longer autonomous operation. This increase in resilience and capability opens new areas of application and deployment while assuring the absence of unreasonable risks.

Action and Interaction

Overview

Action and Interaction technologies are fundamental to the physical nature of robotics. The action of robots in constrained work environments is well understood. It is their interaction in less well constrained or unconstrained environments that sets the greatest challenges. Basic compliant interaction skills and decision making around interaction in such environments and multi-modal[57] perception around human interaction are major

57 Including touch

areas of research and innovation.

At the robotic platform level both Action and Interaction require the integration of multiple robotics and AI technologies. Successful systems utilise physical and computational effects in combination. Processes utilising intelligent mechanisms to tune mechanical performance to create optimal actuated mechanical structures that meet the task requirements is an often-underestimated significant challenge. AI technologies provide better perception of semantic physical interactions and improved planning under constraints, but often - if not always - a successful physical interaction is achieved by a combination of intelligent mechatronics design together with computational intelligence at the task level. In human interaction, contextualised social and behavioural interpretation of both the environment and human co-workers is essential to long term interaction and co-working. AI also has a role to play in making robot decision-making accessible to users, for example through physical and verbal communication. It also has a role in interpreting safe and unsafe operating scenarios. Where large numbers or swarms must be controlled, this can be achieved by using AI based control algorithms, but in addition such algorithms can be designed to exploit the physical mechanisms which govern the interaction between robots, which is especially relevant when the scale of the robot is small.

Dependencies

Action and interaction are fundamentally linked to physical safety and to efficiency in task execution. They depend on all underlying technologies to operate effectively and on compliance with any applicable regulatory constraints related to safety.

Challenges

- Safety in physical interaction is a high priority, especially in applications with close or continuous physical interaction, or where the power of the robot actuators or its kinetic and potential energy could cause harm.
- Cybersecurity of robots in order to protect the safety of robot actions and user privacy.
- Speed and strength (Agility) of collaborative robots needs to be increased, while maintaining safety.
- Novel robot platform configurations or architectures (for example exploiting novel materials, actuators, including bio-inspired actuators and design) or novel construction techniques including Additive Manufacturing, or modular approaches.
- Building concepts of human understandable socialised behaviour for robots and robot behaviour adapted to context and task, for example socialised responses to a dangerous task, or the need for closer interaction.
- Physical interactions with highly flexible or soft materials such as fabric or foodstuff, soft interaction with humans, animals or plants.
- Strategies and methods to control the action and interaction of a massive numbers of small robots to complete tasks collaboratively.
- Modelling operator's behaviour guiding telerobotics to design new paradigms of manipulation that effectively imitate human performance.

Impact/Outcome

Robots will be able to interact with humans more collaboratively, in closer proximity and over longer periods of time. Robots will be able to handle a wider range of complex non-rigid objects, components and structures in a wide range of scales from meter scale to nanometre scale and manipulate them. Interactions will need to reach beyond human speed with equivalent dexterity. Most importantly robots will be able to mutually collaborate including in a large populations, for example in producing advanced structures and materials, and to socialise their interactions with humans in context, for example in handing a tool to a worker who is at the top of a ladder, or physically interacting on a collaborative maintenance task. The ability to certify uncaged robots with the power to harm humans as safe to work with will be a major step change that will open multiple applications. The goal is safe, dependable, predictable and secure robots that can interact usefully with people in natural and intuitive ways.

Systems, Hardware, Methods and Tools

Overview

As has been highlighted above, the mechanical and physical nature of robotics means that robotic hardware and systems have fundamental differences from those in AI and Data and encompass a wide variety of physical platforms including industrial robots, drones, exo-skeletons and all forms of unmanned vehicles. Therefore, many of the systems, hardware, method and tools needed to create them are also unique. In particular, robotics depends on tool chains to both design and configure robot systems and to validate performance; especially where the risks of physical testing are too great during development, for example in interacting with vulnerable people or in hazardous environments.

Dependencies

There are many dependencies on technologies developed externally to robotics. Notably novel hardware development can depend on smart design, materials and novel fabrication methods, while software aspects of robotics depend on real-time system methods and tools and on software/hardware co-design and engineering techniques. Robotics is also highly dependent on configuration and reconfiguration tools that allow users to re-purpose systems and tune performance. Safety assurance methods are inherent to all of these aspects.

Challenges

- Develop robotics specific components optimised for robotics use (e.g. sensing, batteries, actuators etc).
- Developing “by Design” methodologies to address security, privacy, ethics, safety, trust etc. that result in certifiable or certified designs that meet specific regulatory criteria.
- Design methods and systems that create and ensure long term reliability and dependability and associated certification processes, particularly for trustworthiness.
- Increased robustness and reliability of robotic systems to endure real-life operating conditions and handling, particularly in harsh environments.

- Long term energy sustainable robotic systems, in diverse harsh environments from in vivo to underground and submerged environments, for robots of different scales.
- Greater modularity and clear/standardised interfaces in system construction and commoditised components.
- Testing and development environments, both physical and digital, for specific application areas, e.g. nuclear, healthcare, transport, inspection and maintenance in risky environments, etc. where it is impossible to develop in real environments safely.
- End-to-end safety assurance, taking into account hardware, software and system aspects.
- Designing robotic systems for limited resource consumption (data, energy, communication bandwidth, materials) through the use of low power designs (mechanical and electronic) and frugal algorithms.

Impact/Outcome

More efficient platforms and more efficient design processes lead to lower development, integration and deployment costs and higher quality products, especially in safety critical applications. Improved dependability enables long-duration deployment in real-world applications. Greater modularity and interoperability create supply chain opportunities and improve configurability and integration. Intuitive configuration tools reduce the need to use robotics specialists in configuring and reconfiguring systems. Novel robot platform design and increased AI integration, for example at the edge, open opportunities in new markets and applications. Tools and methods that provide end-to-end safety assurance leads to higher efficiency while maintaining a reasonable level of safety.

IMPLEMENTING THE PARTNERSHIP

The Partnership will be open and inclusive and seeks to create a common view that enables success. Europe has excellent research and development, strong underlying innovation systems, worldwide leading verticals and an array of end-user markets able to capitalise on the growth that AI, Data and Robotics offers. The Partnership will promote these strengths, to focus on technical development and create an environment in which AI, Data and Robotics can successfully impact on business, and society across Europe.

The Partnership will work openly and collaboratively with AI, Data and Robotics-related organisations and communities all over Europe to create a common understanding and approach that maximises the gain for Europe. The Partnership will not replace any individual organisation.

The implementation of the Partnership will target both the Digital Europe Programme to build up AI capacity & infrastructure and Horizon Europe for research & innovation. To this end, the Partnership will be based on five strategic Investment Areas (IA).

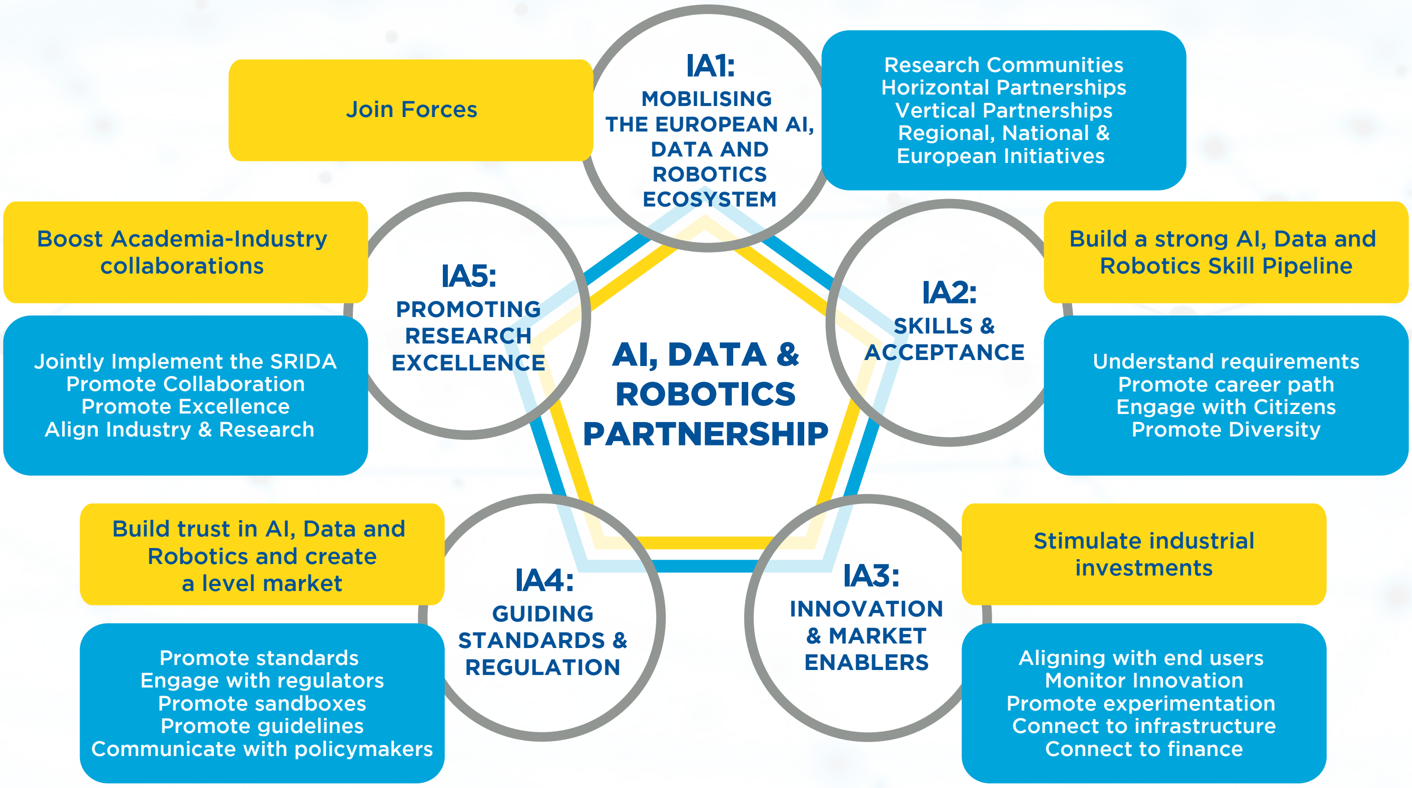

Figure 6: Summary of Investment Areas

IA1: Mobilising the European AI, Data and Robotics Ecosystem

Objective

The Partnership will first and foremost **act as a focus** for industry and service stakeholders, including researchers, who seek to access the opportunity offered by applying these new technologies. The **Partnership will build a focal point for common AI, Data and Robotics strategy** development and implementation in Europe that is based on a good understanding of the unique European strengths and opportunities in AI (“*AI Made in Europe*”), Data and Robotics aligned with the European and global market opportunities for these technologies, as well as reflecting the landscape for AI, Data and Robotics adoption and deployment in Europe.

Action

The Partnership will **mobilise the whole AI, Data and Robotics community** in Europe around the objectives of a common AI, Data and Robotics strategy. It will align with research excellence communities in AI, Data and Robotics to shape strategic challenges, with horizontal partnerships to strengthen synergies between technologies, with vertical partnerships to stimulate access to end-users. The Partnership will connect with existing European initiatives, such as the European AI-on-demand platform, expert networks and other emerging initiatives including start-ups, i-spaces, living labs, member states initiatives and incubators and connect with investors.

Critical to this ecosystem will be a strong connection between the Partnership and the networks of Digital Innovation Hubs and comparable **national and regional initiatives** that will create and develop best-practice at a regional level. In this regard, strong connections to member states and policy makers at European, national and regional level are essential to federate efforts and investments.

Impact

This will **provide strong European leadership for AI, Data and Robotics** that ensures that European technologies have a **clear global voice** that is rooted in their widespread deployment in sectors and regions across Europe. In addition, this will allow Europe to develop a global AI, Data and Robotics position that aligns with fundamental European values and delivers technology, products and services that maintain this goal by seeking to **align academic excellence** and innovation to the needs of both industry and citizens. It will lead to a healthy and **sustainable European AI, Data and Robotics ecosystem**. Formalised and effective cooperation's that are based on a clear understanding of the scope and focus, as well as the strength of each partner, serves as a basis for impact.

IA2: Skills and Acceptance

Objective

The Partnership will take a broad perspective in understanding the AI, Data and Robotics skills challenge facing Europe. It aims to understand the demand and supply of AI, Data and Robotics skills in Europe, with consideration for the need for practitioners to have multi-disciplinary skills, and the necessity to connect non-technical disciplines that impact on AI, Data and Robotics and benefit from them. It needs to ensure that appropriate curricula exist to support the skills demand and to recognise the need for life-long learning and vocational training. It needs to lead the debate to increase citizen, and organisational awareness of the AI, Data and Robotics skills need, and to increase the willingness of organisations to invest in skill building to close the skills gap. Finally, Europe needs to retain AI, Data and Robotics talents by making Europe an attractive place for AI, Data and Robotics workers.

Action

The Partnership will work through its network to ensure that all stakeholders along the value chain, including citizens and users, have the understanding and skills to work with AI, Data and Robotics enabled systems, in the workplace, in the home and online. The Partnership will take a holistic approach to the skills challenge: i) **Understanding**: Actively engage with industry to understand their skill requirements for AI, Data and Robotics and non-AI, Data and Robotics workers. ii) **Promoting**: Create a career path identity for AI, Data and Robotics practitioners that spans research, innovation, and industry. iii) **Engaging**: Stimulate citizen interest in STEM studies, starting from a young age. iv) **Improving**: Impactful R&I that aligns research excellence with industry's needs, ensuring the right environment, remuneration, and career options. v) **Inclusion**: The Partnership will take action to ensure that diversity and inclusion are promoted throughout the skills pipeline.

Impact

The results of these actions will ensure that AI, Data and Robotics (and related) skills are widespread throughout Europe. These actions will increase the capacity of **AI, Data and Robotics education and vocational training** to support a **strong skills pipeline** at all educational levels to increase the supply of talent. The Partnership will ensure that the successful adoption and deployment of AI, Data and Robotics is not limited by a lack of skills in the workforce by **retaining AI, Data and Robotics talent in Europe**. Finally, the partnership will propagate best practice on collaborative change and **increase the awareness of AI, Data and Robotics** within both public and private organisations and with citizens.

IA3: Innovation and Market Enablers

Objective

The objective in this work area is to ensure that the innovation environment in Europe is well founded by ensuring that the necessary assets and infrastructure exist for AI, Data and Robotics, innovation and deployment; for example, data, IoT infrastructure, edge processing, HPC, test infrastructures etc. It is critical that innovators (SMEs, start-ups, etc.) can access this technical infrastructure and gain access to business expertise and finance that can help them react to new developments and opportunities and to enable scale-up.

Successful innovation is dependent on making connections; connections from market stakeholders to end users and to research and technical experts. These connections are bi-directional; just as end users need to understand the range of opportunities new technologies bring, innovators need to be aware of the opportunities that new business models could bring.

Action

The Partnership will achieve these objectives by **aligning with end users** to obtain insights into business and market logic and by engaging with stakeholders along the AI, Data and Robotics innovation chain fostering cooperation and developing support for translation and deployment. The Partnership will also carry out **monitoring of the innovation landscape** in Europe to assess progress and the health of AI, Data and Robotics innovation, adoption and deployment. It will also achieve impact by **promoting experimentation** and connection to existing and future AI, Data and Robotics infrastructure; Digital Innovation Hubs, on- demand platforms, data platforms, pilots etc. It will support and enable access to this infrastructure as well as to data and tools essential for AI, Data and Robotics innovation. It will also seek to **connect to financial institutions**, such as the EIB and EIF and VC funds, to create synergies and raise awareness of the AI, Data and Robotics investment opportunity in Europe.

Impact

These actions will **stimulate industrial investment** and private funding for AI, Data and Innovation in Europe and impact on the success of innovators translating research to market. They will contribute to creating a connected and **rich innovation ecosystem for AI, Data and Innovation** across Europe, contributing success by providing innovators with access to data and key innovation resources.

IA4: Guiding Standards and Regulation

Objectives

The Partnership seeks to **create a level market** in Europe shaped around common worldwide standards and regulation and around common approaches to the certification and validation of AI, Data and Robotics-based products and services. This enables the smooth translation of innovation into the market by enabling innovators to more rapidly deploy products and services across and beyond Europe. It also enhances trust in AI, Data and Robotics by creating understandable guarantees for operation and behaviour. The impact of regulation and certification on product development and deployment is highly complex, especially when autonomous decision making or learning are involved. The Partnership will **increase understanding of regulation** and recognises the need for **high-quality testing environments** to be available and accessible across all sectors and regions in Europe.

Action

The Partnership will work to consolidate discussion around the development of common worldwide standards, especially around data, interoperability and trustworthiness, as these help to build supply chains and trust. It will engage in dialogue with regulators and end users to level out regulation and will seek to establish greater use of regulatory sandboxes and access to them across sectors and regions in Europe and beyond. Above all, it will promote the use of regulation to support innovation.

The Partnership will promote the use and development of sector-specific AI, Data and Robotics guidelines and related impact assessments and will engage with businesses seeking to operationalise and pilot them. It will contribute to policy debates around the impact of AI, Data and Robotics and AI, Data and Robotics-driven value creation, including those around ethics, privacy and trustworthiness. Most importantly it will work with stakeholders in the AI, Data and Robotics Ecosystem infrastructure (Digital Innovation Hubs etc.) to identify areas where regulation is impacting on deployment and will **communicate to policymakers** where barriers to uptake and deployment are identified.

Impact

These actions will promote the awareness of regulation and standards within the AI, Data and Robotics Ecosystem, having a double impact: (i) making innovators more prepared for market entry, thereby accelerating time to market; (ii) raising awareness of regulators to the state and potential of technology, enabling the creation of the necessary, tailored regulation in an appropriate and timely manner. The wider use of AI, Data and Robotics guidelines and impact assessments will **help to build trust in AI, Data and Robotics**, both with stakeholders and citizens, while the wider use of standards will promote data flow and interoperability. The overall impact will be to **level the market for AI, Data and Robotics** in Europe and create scale through improved trust and the development of cross-sector supply chains.

IA5: Promoting Research Excellence

Objectives

A key objective of the Partnership is to promote research excellence in the cross-sector technology enablers that are of strategic importance for trustworthy European AI, Data and Robotics. Europe needs to leverage its existing **scientific excellence in these technologies**, strengthen scientific cooperation, reduce fragmentation of research, and ensure access to world-class research infrastructure (HPC, testing infrastructure, European Network of AI Excellence Centre, etc.). Europe must enable and encourage AI, Data and Robotics researchers to work across disciplines. The Partnership needs to ensure that research is **aligned with industry** needs and focus on solutions that boost deployment.

Action

The Partnership will work with the academic and industrial communities to build actions to i) promote collaboration, networking and inter-disciplinarily, ii) promote European AI research excellence, and iii) align industry needs and research outcomes. These actions will be achieved by implementing the joint SRIDA collaboratively with the research and industrial stakeholder communities.

Impact

These actions will result in improved Academia-Industry collaborations that create a global AI, Data and Robotics leadership position for Europe on a foundation of academic excellence grounded with industrial relevance. It will improve the rate of technology transfer and adoption of AI, Data and Robotics **from the lab to real-world deployments**.

OPEN COLLABORATION ON AI, DATA, AND ROBOTICS

In order to deliver the operational objectives of the Partnership it is important to engage with a broad range of stakeholders. Each collaborative stakeholder brings a vital element to the functioning of the Partnership and injects critical capability into the eco-system created around AI, Data and Robotics by the Partnership.

The mobilisation of the European AI, Data and Robotics Ecosystem is one of the core objectives of the Partnership. Its actions will bring together all the different communities and stakeholders; those already involved and those who will be affected by or stand to benefit from AI, Data and Robotics. An important focus of this is to support the horizontal components of the European AI, Data and Robotics Ecosystem to strengthen synergies between technologies, and to enable effective cross-sector value creation while seeking to explore constraints and address challenges.

Coherence and Coordination with European Partnerships and other Programmes

As part of the Strategic planning of Horizon Europe a portfolio of 49 European Partnership candidates have been identified and are now been taken into the next steps for preparations[58]. The AI, Data and Robotics Partnership focuses on all sectors of economy, business, environment and society, and combines key enabling technologies central to the digital transformation. Coordinating actions with those initiatives is of relevance to achieve the ultimate objectives of partnership and 16 partnerships have been initially identified and will be prioritised in identifying synergies, aligning roadmaps, and defining specific collaboration actions.

Candidate partnership	Cluster Horizon Europe	Description and synergies
European Partnership for Innovative Health	Health	Partnership for Health Innovation aims to enable the integration of cross-sectoral technologies, know-how, products, services and work-flows for people-centred health care. It addresses core challenges of the AI, Data and Robotics Partnership such as the access to (big) data, data quality, skills, interoperability, lack of standards, data protection, privacy, and ethical challenges linked to AI. Robotics technology can help to increase efficiency and quality of services provided.
European Partnership on Health and Care Systems Transformation	Health	The partnership on Health and Care Systems Transformation aims to contribute to the transition towards more sustainable, resilient, innovative and high-quality people-centred health and care systems. Health data, use of big data, the creation of a European Health Data Space and relevant areas of work for this partnership. Robotics technology is relevant to work towards affordable high-quality health and case services.

58 https://ec.europa.eu/info/horizon-europe-next-research-and-innovation-framework-programme/european-partnerships-horizon-europe_en

European Partnership on Rare Diseases	Health	The main goal is to improve the life of rare diseases patients by developing diagnostics and treatments for rare diseases, through multidisciplinary R&I programs with all the relevant stakeholders. It will deal with aspects of data access, data infrastructures, data sharing, and data standards and interoperability. Foreseen to start in WP 2023/24.
European Partnership for High Performance Computing	Digital, Industry, Space	The partnership for High Performance Computing sets ambitious plans by 2027 for Europe aiming to develop, deploy, extend and maintain a world leading federated and hyper-connected supercomputing infrastructure; support the autonomous production of innovative and competitive supercomputing systems based on indigenous European components, technologies and knowledge; and, widen the use of this supercomputing infrastructure to a large number of public and private users. In addition, mobile applications can benefit from HPC on the edge e.g. to allow for real-time applications. A strong collaboration in between the HPC and Data/Data-driven AI communities was implemented during H2020 (e.g. MoU ETP4HPC and BDVA, participation of BDVA in the EuroHPC JU, etc.) and will be strengthened in HE towards all data, all AI and all robotics. [Details in next section]
European Partnership for Key Digital Technologies	Digital, Industry, Space	The overarching objective of the KDT partnership is to support the digital transformation of all sectors of the economy and society, make it work for Europe and address the European Green Deal. With a main focus on electronics, components and systems the collaboration between the KDT and AI, Data and Robotics partnerships will establish the basis for leveraging synergies at different levels in particular in the areas of distributed intelligence, real-time applications and safety-critical systems. (Details in next section)
European Partnership for Smart Networks and Services	Digital, Industry, Space	The partnership aims to support technological sovereignty concerning smart networks and services in line with the EU industrial strategy and the 5G cyber-security toolbox. It will enable European players to develop the technology capacities for 6G systems as the basis for future digital services towards 2030. It will also allow that lead markets for 5G infrastructure and services can develop in Europe. Smart Networks and Services is a critical cross-sectorial infrastructure and research enabler for AI, big data, next-generation cooperative robots. Additional AI is a crucial technology for future cost-effective communication systems and networks. (Details in next section)
European Partnership for Photonics	Digital, Industry, Space	This partnership aims to speed up photonic innovations, securing Europe's technological sovereignty, raising the competitiveness of Europe's economy, and ensuring long-term job and prosperity creation. Photonics are important components in Robotics (sensing and perception) and AI system (e.g. support intelligent data and imaging processing, etc.). Photonics sensors also generate vast amounts of data and information with a large variety of formats that feed into the Data ecosystems. Additional photonics enables and advances capacity in data transmission, bringing new opportunities for distributed data analytics real-time systems.

European Partnership Made in Europe	Digital, Industry, Space	The partnership will be the driving force for sustainable manufacturing in Europe. It will contribute to a competitive and resilient manufacturing industry in Europe and affects many value chains. Another priority is circular economy and following a circular by design approach. Data analytics, AI, machine learning, and data management and sharing, intelligent and autonomous handling, robotics and digital twins are key enabling technologies in this partnership. The Data, Robotics, and manufacturing industries communities have collaborated during H2020 through BDVA, euRobotics and EFFRA (e.g. MoU EFFRA-BDVA) and will continue close cooperation in Horizon Europe.
Processes4Planet – Transforming the European Process Industry for a sustainable society	Digital, Industry, Space	The partnership aims at circularity and an extensive decarbonisation of European process industries, with a strong focus on competitiveness. Digitalisation of process industries require integration of enabling technologies such data sharing frameworks, data analytics, AI and robotics.
European Partnership for Globally competitive Space Systems	Digital, Industry, Space	This partnership aims to support the competitiveness of the Space and reinforce EU capacity to access and use space. This partnership will benefit from the AI, Data and Robotics technologies in in-orbit operations (manufacturing, assembly, reconfiguration, etc.). Additional AI will be key for processing imagery on-board Earth Observation satellites. Furthermore, there is a benefit in transfer of space technology to other markets and vice versa.
European Partnership for Transforming Europe's Rail System	Climate, Energy, mobility	This partnership aims at delivering technological and operational solutions that respond to a new Concept of Operations for Rail and at leading the transition towards integrated, digital, autonomous, sustainable mobility. This requires an integrated systematic approach, including decarbonisation, automation and digitalisation (big data, Artificial Intelligence, and robotics, etc.)
European Partnership for Integrated Air Traffic Management	Climate, Energy, mobility	Main objective is the digital transformation of Air traffic management making the European airspace the most efficient and environmentally friendly, supporting the competitiveness and recovery of the European aviation sector in a post-COVID crisis Europe. It will make use of key digital technologies such as big data, automation, AI, etc. AI for aviation, virtualisation and cyber-secure data sharing are (to mention some) key focus areas in this partnership.
European Partnership on Connected, cooperative and Automated Mobility (CCAM)	Climate, Energy, mobility	It aims to harmonise European R&I efforts to accelerate the implementation of innovative CCAM technologies and services. CCAM integrates and advances technologies in the mobility and automotive sector combining AI, Data and Robotics cross-sectorial technology enablers (such as perception-action, real-time decision making, systems integration, etc). Future synergies and alignment will be established with their Cluster 2 (Vehicle technologies) and Cluster 5 (Key enabling technologies).
Agriculture of Data (European Partnership on environmental observations for sustainable EU-agriculture)	Food, bioeconomy, natural resource, agriculture and environment	This partnership will support sustainable agriculture in the EU as well as policy monitoring and implementation by using digital and data technologies in environmental observation. The partnership will generate EU-wide data sets and information through combining geospatial and Earth Observation datasets and employ data technologies to provide solutions to the agricultural sector. Data collection, integration of information from different sources, management, sharing, processing and the usage of AI are very central to this partnership.

European Open Science Cloud Partnership	Across themes	It aims to deploy and consolidate by 2030 an open, trusted virtual environment to enable the estimated 2 million European researchers to store, share and reuse research data across borders and disciplines. Cooperation will be established in alignment with the EOSC Action Area 14 (Widening to the Public and Private Sectors). European Data Spaces, Data4AI, Knowledge and Learning as well as the Systems, Hardware, Methodologies and Tools cross-technology enablers are central areas of collaboration in between both partnerships.
EIT Digital-KIC	Across themes	EIT Digital's mission is to drive digital innovation and develop entrepreneurial talent in order to enhance both economic growth and quality of life across Europe. Addressing the overall spectrum of digital technologies (notably highlighting technologies such as AI and robotics) this partnership tackles aspects of importance for the AI, Data and Robotics Partnership such as bringing European values to the digital world, supporting digital enterprises and entrepreneurs and the adaptation of the European education system to the digital reality
EIT Manufacturing-KIC	Across themes	EIT Manufacturing will be delivering solutions to transform today's industrial forms of production towards more knowledge intensive, sustainable, low-emission, trans-sectoral manufacturing and processing technologies, to realise innovative products, processes and services. Full digitalisation of manufacturing is one of its strategic objectives as well as skilling up the workforce to face the new challenges of digital technologies such as AI.

Context of AI, Data and Robotics within the European Technical Ecosystem

The impact of AI, Data and Robotics is widely acknowledged and places these technologies as key drivers of the digital revolution. However, in order to extend their impact other technical competencies must be connected and integrated into AI, Data and Robotics applications, systems and infrastructure. AI, Data and Robotics therefore form part of a broader mix of technology that includes cybersecurity, connectivity, the Internet of Things, electronics, semi- conductors, computation, storage, software, and systems design. Each of these areas in their turn utilise or contribute to AI, Data and Robotics.

Each of these technical areas has its own market development progression. Each is creating new markets and creating transformation within them and most have a European partnership to create coherence. As these market transformations progress and the complexity of deployable applications increases there is growing need to integrate with a wider range of technologies. For example early markets may be satisfied by using of the shelf components and systems, but as the demand for greater performance and lower cost grows then the need to utilise more bespoke hardware, or more integrated communications, or dedicated analytics becomes the only way to expand deployment into new application areas. Initially each picks the "low hanging fruit" but to reach out into more complex application areas requires a more integrated technical approach. AI, Data and Robotics may only be needed at the most complex levels of application to bring greater levels of autonomy, understanding and control to complex multi-faceted systems for example in road transport, manufacturing logistics and healthcare diagnosis etc.

An effective deployment of AI, Data and Robotics within the digital economy can only be achieved when there is a coherent understanding of how these different technologies complement and interact with each other in the context of applications. This can be described as cooperative intelligence. For example the balance between edge and cloud based AI will depend on the criticality of timeliness in the task and this will have different approaches in different application areas, for example between industrial applications and autonomous vehicles. Other factors such as the level of autonomy and human interaction will also determine the balance of technologies needed.

The Partnership forms part of a wider ecosystem of partnerships that cover all aspects of the technology application landscape in Europe. Many of these partnerships will rely on AI, Data and Robotics as critical enablers to their own endeavours. Both horizontal (technology) and vertical (application) partnerships intersect around AI, Data and Robotics. The impact of AI, Data and Robotics in each of these partnerships will drive the need for connectivity between the Partnership and each of them.

This section of the SRIDA sets out the nature of some of these collaborations and the partners that the Partnership will seek to collaborate with. The nature of these collaborations will be governed by the identified synergies and benefits and are shaped by the Work Areas set out in the section "Implementing the Partnership".

Horizontal Collaborations

As described above the core of this connectivity are collaborators that connect key supporting technologies. These are characterised as "horizontal collaborations" and reflect the need to work closely with organisations that champion co-technologies that are essential to the deployment of AI, Data and Robotics.

AI, Data and Robotics do not, in themselves, constitute complete systems of operation. In order to leverage the full potential of a completely digitised European Industry, an approach is needed which integrates a range of horizontal technologies.

The champions of these key co-technologies, critical to the deployment of AI, Data and Robotics, operate within existing associations and horizontal European partnerships and it is the development of these important strategic relationships that is set out in the following sections:

- **Cybersecurity with ECSO:** Active engagement with Cybersecurity is a critical enabler for AI so that organisations can reliably safeguard critical infrastructure, protect sensitive information and assure business continuity. The deployment of data, robotics and AI applications is not possible without a high level of trust, and an effective Cybersecurity regime underpins the development of that trust.
- **Smart networks and services with 5G Infrastructure Association:** Smart communications will be required to provide high speed and low latency networks to be delivered by 5G infrastructure, at the same time AI will be a key enabler for cost-effective communication networks.
- **Electronics, components, and systems with AENEAS, ARTEMIS-IA, and EPoSS:** The combination of Nano-electronics, Embedded Intelligence and Smart Systems Integration together with AI, Data and Robotics is central to continued digitalisation that will help industries to maintain their competitive edge.
- **High-performance computing with ETP4HPC:** High-Performance Computing (HPC)

capabilities are needed by specific AI, data and robotics applications where faster decision-making is crucial and extremely complex data sets are involved, while AI capabilities improve the development and deployment of HPC solutions.

- **Internet of Things with AIOTI:** The alignment with Internet-of-Things technologies is needed to foster the seamless integration of IoT with data, robotics and AI technology.
- **Machine vision with EMVA:** Machine Vision with The European Machine Vision Association: Vision components can be seen as a major source to generate data and knowledge about the environment and are a basis for decision making and control in many application areas. Therefore, alignment with the European Machine Vision Association (EMVA) is of mutual benefit.
- **Software and systems with NESSI:** The creation of a new class of self-learning, self-optimising and self-adapting systems will create the need for novels ways of software and system development. Software engineering will need to be "re-engineering" concerning software design and architecture, data lifecycles, quality assurance, and deployment on dedicated hardware.

The following sections detail the key horizontal collaborations identified to date and sets out the rational for cooperation and alignment.

Cybersecurity with ECSO

The European Cyber Security Organisation (ECSO) ASBL is a fully self-financed non-for-profit organisation under the Belgian law, established in June 2016.

ECSO represents the contractual counterpart to the European Commission for the implementation of the Cyber Security contractual Public-Private Partnership (cPPP). ECSO is an umbrella organisation: it's members include a wide variety of stakeholders representing the public and private sectors, as well as European Member State's local, regional and national administrations. The main objective of ECSO is to support all types of initiatives or projects that aim to develop, promote, encourage European cybersecurity, well beyond the initial objectives of the cPPP focussed on R&I issues. ECSO's particular aim is to foster and protect from cyber threats the growth of the European Digital Single Market, to develop the cybersecurity market in Europe and of a competitive European cybersecurity and ICT industrial base. ECSO gathers and stimulates cooperation of the European Community. It also aims to support the development and implementation of European cybersecurity solutions for the critical steps of trusted supply chains, in critical applications, in particular where Europe is a leader. ECSO sees Data, Robotics and AI as strategic elements for the growth of Europe and as such considers the protection of their use as well as the dangers of their misuse as one of the most important priorities of our Community.

Why is the cooperation needed?

Cybersecurity and Artificial Intelligence naturally complement each other and are closely related. Robotics and Artificial Intelligence could be used, and could even be more efficient in performing automated and sophisticated attacks to a system rather than protecting it, creating novel and extended security threats. At the same time AI, Data and Robotics can be used to significantly improve cybersecurity technologies as well as parts of the processes enabling cyber and physical security, for instance by providing automatic responses to security incidents or even the deployment of security controls in the case of vulnerabilities to minimise risk exposure. Given the increasing number and types of AI systems, cybersecurity methods will play a key role in ensuring technical robustness, resiliency, and dependability. The value of AI relies on high quality data with good provenance; thus, the impact of falsified data and trust in data is a central consideration. It is therefore important to define concepts of measurable trust, reputation- and evidence-based trust, computational models of trust, assurance models, fake information and deep fake. AI-driven systems face all known cybersecurity challenges, such that data should be secured at rest and in motion. In addition to the challenges already highlighted, it is vital to consider the interplay between safety and security, which will be particularly important in robotics. AI-driven systems should comply with existing regulations and legislations in a demonstrable way, for example through a continuous assessment to demonstrate that fundamental rights such as privacy are appropriately addressed. Some of them need to be auditable, though court-capable forensics techniques.

None of the disciplines can solve all these challenges alone. The collaboration is needed and will be built upon the already ongoing joint activities between ECSO with BDVA and euRobotics.

Smart Networks and Services with 5G IA (European Partnership for Smart Networks and Services)

The 5G Infrastructure Association (5G IA)[59] represents the private side in the European H2020 5G Public-Private Partnership (5G PPP) and it is the main promoter of the Horizon Europe candidate Partnership on Smart Networks and Services. This provides the business dimension on top of the technical work delivered by European research to facilitate faster uptake of results and point the way to disruptive research directions. The primary objective of the 5G IA is to promote and support European leadership for the development, deployment and evolution of 5G and 6G and to ensure a strong European voice on 5G around the world. In February 2019 the 5G IA published a Position Paper for a European Partnership on Smart Networks and Services under Horizon Europe aiming at developing the essential digital infrastructure for the Human Centric Internet, enabling the development of European strategic value chains for the 'Industrial Internet of Things' and for 'Connected, Automated and Electric Vehicles"[60], among other key sectors. The Smart Networks and Services partnership aims to support technological sovereignty concerning smart networks and services. It will contribute to enabling the digital and green transitions, address the coronavirus crisis both in terms of technologies for health crisis response and of economic recovery. It will enable European players to develop the technology capacities for 6G systems as the basis for future digital services towards 2030. It will also allow that lead markets for 5G infrastructure and services can develop in Europe.

Why is cooperation needed?

Smart Networks and Services is a critical cross-sectorial infrastructure and research enabler for artificial intelligence, big data, next-generation cooperative robots, high-performance computing and cybersecurity. Joint research between Smart Networks and Services, IoT, AI, Data and Robotics assets will create more value, increased sector knowledge, and ultimately more ground for new sector applications and services. Looking at Smart Networks as a vertical market for AI opens joint scientific challenges in trustworthy hybrid decision making. Two key areas where such decisions will be impactful are i) decentralised and automated network management and optimisation, and ii) intelligent spectrum management. Research on those areas will help to lower barriers in verticals investing in 5G and future communication technologies.

Synergies can be leveraged in different areas; Smart communication is a key technology for AI, while AI is a crucial technology for future cost-effective communication systems and networks. Systems will increasingly be based on distributed Artificial Intelligence (AI) and Machine Learning (ML). Multiservice and Edge Computing will allow the storage and processing of data locally at the edges of the network to provide fast reaction and efficient use of network resources. Robust and reliable communications are needed as a critical enabler for trustworthy AI to protect the integrity and privacy of data across technologies, borders, and value chains. Finally, standards in 5G have developed very soundly, while in AI, Data and Robotics the landscape is much more fragmented. Both partnerships see benefit in working together in some verticals (e.g. Automotive, Industry 4.0), sharing information about standardisation bodies they are involved in, and pursuing industry consensus.

59 https://5g-ia.eu/

60 Inception impact assessment Smart Networks and Services PPP (https://ec.europa.eu/info/law/better-regulation/initiatives/ares-2019-4972300_en)

Electronics, Components, and Systems with AENEAS, ARTEMIS-IA, and EPoSS (European Partnership for Key Digital Technologies)

Key Digital Technologies (KDT)[61] is the proposed European Partnership under the next Multi-annual Financial Framework of the European Union to support the development of European strategic value chains for microelectronics and the industrial 'internet of things', as identified by the Strategic Forum for Important Projects of Common European Interest (IPCEIs). The proposed KDT partnership will build on the experience gained from the Joint Undertaking on Electronics Components and Systems for European leadership (ECSEL) and, satisfy the more demanding societal, economic and technological impact criteria of Horizon Europe.

The ECSEL Joint Undertaking - the Public-Private Partnership for Electronic Components and Systems – funds Research, Development and Innovation projects for world-class expertise in these key enabling technologies, essential for Europe's competitive leadership in the era of the digital economy. The members of ECSEL JU are the three associations AENEAS[62], ARTEMIS-IA[63], EPoSS[64] and the European Union (through the European Commission) and 26 Member States and 4 Associated Countries to H2020.

Why is cooperation needed?

The availability of the key digital technologies is a central lever for the cross-sectorial deployment of AI, Data and Robotics. By combining Nano-electronics, Embedded Intelligence and Smart System Integration, AI, Data and Robotics methods, paradigms and assets, substantial new resources (infrastructure, knowledge and R&I) can be developed that will help industries to maintain their competitive edge. Thus, advancing key digital technologies and their use will enhance novel technologies such as AI, Data and Robotics. Research into electronics components and systems and relevant aspects of software technologies and photonics are featuring increasingly in the digital transformation of the economy and society. By increasing its digitalisation efforts Europe will facilitate access to a wide range of data sources that can then be used as input for developing a wide range of AI applications. At the same time, emerging AI value opportunities will stimulate the adoption of key digital technologies.

The collaboration between the KDT and AI, Data and Robotics partnerships will establish the basis for leveraging synergies at different levels: the development of innovative cognitive functions for smart systems can build upon research in sensing, measurement and perception; while the expertise needed to assemble different technologies to build products and services can be leveraged for developing innovative systems, methodologies and hardware for AI systems. In addition safety, security and reliability, as well as the embedding of AI applications into the edge, are central requirements for both European Partnerships.

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61 Key Digital Technologies Inception Impact assessment, https://ec.europa.eu/info/law/better-regulation/initiatives/ares-2019-4972315_en

62 **AENEAS** is an Association, established in 2006, providing unparalleled networking opportunities, policy influence & supported access to funding to all types of R&D&I participants in the field of micro and nanoelectronics enabled components and systems. See https://aeneas-office.org

63 **ARTEMIS Industry Association** strives for a leading position of Europe in Embedded Intelligence. The multidisciplinary nature of the membership provides an excellent network for the exchange of technology ideas, cross-domain fertilisation, as well as for large innovation initiatives. See https://artemis-ia.eu

64 **EPoSS,** the European Technology Platform on Smart Systems Integration, is an industry-driven policy initiative, defining R&D and innovation needs as well as policy requirements related to Smart Systems Integration and integrated Micro- and Nanosystems. See www.smart-systems-integration.org

High-Performance Computing with ETP4HPC (European Partnership for High Performance Computing)

ETP4HPC – the European Technology Platform (ETP) for High-Performance Computing (HPC) - is a private, industry-led and non-profit association with the mission to foster European HPC technology-related research, development and innovation in order to maximise the economic and societal benefit of HPC for European science, industry and citizens. Their primary focus is to propose research priorities and work programme contents in the area of HPC technology and usage.

- The EuroHPC Joint Undertaking (EuroHPC JU) is a joint initiative between the European Commission and European member states to develop a World Class Supercomputing Ecosystem in Europe.

The partnership aims by 2027[65]:

- to develop, deploy, extend and maintain a world leading federated and hyper-connected supercomputing, quantum computing, service and data infrastructure ecosystem in the EU.
- support the autonomous production of innovative and competitive supercomputing systems based on indigenous European components, technologies and knowledge and the development of a wide range of applications optimised for these systems.
- widen the use of this supercomputing infrastructure to a large number of public and private users, and support the development of key skills that European science and industry need.

Why is cooperation needed?

The convergence of HPC and Artificial Intelligence (AI) is critical for applications that rely on Big Data and High-Performance Data Analytics (HPDA)[66].

AI and HPC are by their nature synergetic. On one side, today, both deployment fields take advantage of heterogeneous system architectures based on heavy use of accelerators. Large Deep Learning workloads perform best on these system structures as do large scale simulation codes for both scientific and industrial use cases. On the other side AI and HPC together with Data Analytics are elements of a "digital continuum" workflow based on an entire infrastructure ecosystem stretching from data centres to cloud, fog and edge computing.

In some sectors, AI, Data and Robotics applications are expected to move towards more compute-intensive algorithms to reach deeper insights across descriptive (explaining what is happening), diagnostics (explaining why it happen), prognostics (predicting what can happen) and prescriptive (proactive handling) analysis. The adoption of specific HPC-type capabilities by AI, data and robotics technologies is likely to be of assistance where faster decision-making is crucial and extremely complex data sets are involved – i.e. extreme data analytics combining AI and HPC in earthquake prediction and the reconfiguration of complex neural networks. From humble beginnings (such as finding hidden and very intricate patterns in simulated and observed data), the first generation of combined applications is now emerging. "AI for HPC" where AI capabilities improve the development and deployment of HPC solutions. AI systems will have necessarily to meet safety, trustworthiness, reliability and dependability requirements. AI for HPC will affect all HPC tools, processes, methodologies, architectures, infrastructures and standards. Power consumption will also be a significant challenge.

65 https://ec.europa.eu/info/horizon-europe-next-research-and-innovation-framework-programme/european-partnerships-horizon-europe/candidates-digital-industry-and-space_en

66 ETP4HPC and BDVA are private members of the EuroHPC JU, and both associations have representatives in the EuroHPC Research and Innovation Advisory Group (RIAG). First common publication: http://www.bdva.eu/sites/default/files/bigdata_and_hpc_FINAL_16Nov18.pdf

Internet of Things with AIOTI

AIOTI is the multi-stakeholder platform for stimulating IoT Innovation in Europe, bringing together small and large companies, start-ups and scale-ups, academia, policymakers and end-users and representatives of society in an end-to-end approach. The mission of the Alliance of Internet of Things Innovation (AIOTI) is to foster the European IoT market uptake and position by developing ecosystems across vertical silos, contributing to the direction of H2020 large-scale pilots, gathering evidence on market obstacles for IoT deployment in the Digital Single Market context, championing the EU in spearheading IoT initiatives, and mapping and bridging global, EU and Members States' IoT innovation and standardisation activities. AIOTI working groups cover various vertical markets from Smart Farming to Smart Manufacturing and Smart Cities, and specific horizontal topics on standardisation, policy, research and innovation ecosystems. The AIOTI was launched by the European Commission in 2015 as an informal group and established as a legal entity in 2016. It is a significant cross-domain European IoT innovation activity.

Why is cooperation needed?

Internet of Things (IoT) technology, which enables the connection of any smart device or object, will have a profound impact on many sectors in the European economy that will trigger significant growth in the amount of data. According to Gartner[67], there will be over 14 billion connected devices by the end of 2019, and over 25 billion by the end of 2021. This growth in data will lead to future market expansion in the IoT business; for instance, the global IoT market was worth over $150 billion in 2018 and is expected to exceed $1.5 trillion by 2025[68]. Fostering this future market growth requires the seamless integration of IoT technology (such as sensor integration, field data collection, Cloud, edge and fog computing) with AI, Data and Robotics technology. By jointly building IoT-enabled Data Marketplaces along four well-defined maturity stages[69] the horizontal integration of IoT and AI, Data, Robotics technology can be guided and fostered.

67 https://www.gartner.com/en/newsroom/press-releases/2018-11-07-gartner-identifies-top-10-strategic-iot-technologies-and-trends
68 https://iot-analytics.com/state-of-the-iot-update-q1-q2-2018-number-of-iot-devices-now-7b/
69 European IoT challenges and opportunities 2019-2024, An IoT Enabled Future. Alliance for Internet of Things, July 2019.

Machine Vision with EMVA

The European Machine Vision Association (EMVA) is a non-for-profit and non-commercial association representing the Machine Vision industry in Europe. The association has been founded in 2003 in Barcelona by industry representatives from all over Europe as a network to promote the development and use of machine vision technology.

The EMVA is open for all types of organisations having a stake in machine vision, computer vision, embedded vision or imaging technologies: manufacturers, system and machine builders, integrators, distributors, consultancies, trade press, research organizations and academia. All members – as the 100% owners of the association – benefit from the networking, cooperation and the numerous and diverse activities of the EMVA.

Why is cooperation needed?

Vision technology is part of many smart devices or objects, and has a significant impact on many sectors in the European economy, including autonomous cars, transportation in general, agri-food, healthcare, in manufacturing, maintenance and inspection, quality control, the security sector, smart cities, human machine interaction and many others. Vision components can be seen as a major source to generate data and knowledge about the environment and are a basis for decision making and control, this includes image or video acquisition technologies, such as 3D data generation, spectral imaging, x-ray, or controlled illumination. 99% of all captured raw data is pixels, 75% of all data entering the human brain is vision data. Consequently, 49% of all AI patents relate to computer vision.

A seamless integration of vision technology in applications is a must for the development of such systems, where especially for mobile systems, energy consumption and communication structures are important factors to be considered.

Europe is well known to be the world leader in the development and deployment of vision technologies, with a particularly strong presence in the industrial sector. Europe has led the world, both in the development of hardware and software over the past 30 years. This trend continues, but the rapid development of vision based AI technology both in China and North America poses risks to technology leadership as well as opportunities, for example in the development of worldwide standards to enable clear guidance to implementation and adoption of vision technologies.

The EMVA provides a strong eco-system of manufacturers, end users, and research institutes, underpinned by a very active standards development programme and various other activities. The opportunity exists to leverage this network of members to help promote the wider vision of the Partnership, increase participation and cross-sector networking, and ultimately align the strategies of European vision technology players with the Partnership agenda. At the same time, many of the companies operating in the broader AI, Data and Robotics eco-system share suppliers, customers, end-users, and sources of talented employees, as well as technical approaches to problem solving which leads to a natural cooperation opportunity.

Software and Systems with NESSI

NESSI, the Networked Software and Services Initiative, is the European Technology Platform, for the digital information society and an economy powered by software, services and data. The main aim of NESSI is to promote research, development and innovation in the field of software, cloud/edge/fog computing, data and digital services in order to strengthen the competitiveness of the European industry in this field and represent industry and other organisations active in this field. NESSI is registered as an international not-for-profit association under Belgian law. NESSI has a strong background of shaping European research on software systems and methodologies, as well as software deployment on virtualised hardware, such as cloud and fog computing. NESSI thereby provides complementary expertise for shaping the Partnership SRIDA, in particular contributing to the cross-sectorial AI, Data and Robotics technology enablers "Systems, Methodologies and Hardware".

Why is cooperation needed?

The NESSI view is that without software, there is no AI[70]. It is important to recognise both, the challenges of AI software and what AI can bring to software. Embedding AI algorithms into complex software systems is fundamental to delivering AI-based innovations and thus for the achievement of the vision for AI. AI will empower a new class of self-learning, self-optimising and self-adapting systems, which calls for novel ways of developing software and systems. The governance of AI-based systems and suitable software architectures and software engineering methodologies for AI are challenges which need to be explicitly addressed.

Addressing these challenges requires "re-engineering" software engineering concerning software design and architecture, software and data lifecycles, quality assurance, as well as deployment on dedicated hardware. As an example, AI-based self-adapting software systems help master the complexity, dynamicity and uncertainty entailed in developing software systems. By learning at run-time, they can handle situations that cannot be anticipated at design time, due to incomplete knowledge and uncertainty about the system environment. However, such learning at run-time requires novel ways of developing, debugging and testing these systems; e.g., determining causality and liability for autonomous actions and decisions.

70 NESSI Whitepaper, "Software and Artificial Intelligence", 2019, http://www.nessi.eu/Files/Private/NESSI%20-%20Software%20and%20AI%20-%20issue%201.pdf

Engagement with European Funded Projects

A vital part of the European AI, Data and Robotics Eco-system are the projects funded through the European Commission Framework programmes. These public investments stimulate interaction and exchange within the Eco-system boosting the adoption of AI, Data and Robotics and the development of excellence. However their success is pivotal on generating market impact that both stimulates private investment and generates new market opportunities. It is not sufficient for these investments to solely deliver greater academic connectivity and exchange. They must deliver real economic impact and novel technology that creates step changes in AI, Data and Robotics market places. They must also focus on cross-fertilising opportunity between multiple vertical sectors and in the horizontal infrastructure, service and component markets.

The Partnership will engage strongly with these major public AI, Data and Robotics infrastructure investments and work closely with the consortia that operate and develop them to ensure that the impacts are maximised. All associations, will continue to actively stimulate connections between their members and these infrastructures and will guide private investment to boost Europe's overall private spending in AI, Data and Robotics, to reach Commission targets.

To achieve this these publicly funded infrastructures, such as the on-demand platform, must be open, secure, valuable and effective assets managed for the whole eco-system and to the benefit of both academics and industrial companies both large and small. Well-founded accessibility mechanisms and low barriers to entry are essential so that start-ups and SMEs can rapidly bootstrap their AI skills and deployment. This should be aided through the networks of AI-based Digital Innovation Hub networks such as those set up in AI, Data and Robotics, and through future networks of Digital Innovation Hubs in each region. An important step for the technology uptake for SMEs is the access to experimentation and testing of new technologies in real-life environments planned to be implemented through the Digital Europe Programme (Testing and Experimentation Facilities or TEF). It must leverage the emerging European Data Spaces to enable new data value chain opportunities, building upon existing initiatives and investments (data platforms, i-Spaces, big data innovation hubs) for AI, Data and Robotics Innovation.

Equally critical is open access to research stimulated through the AI Centres of Excellence Networks. Success for AI, Data and Robotics in Europe is pivoted on the rapid transfer of knowledge and skills from academia to industry and the effective propagation of industrial challenges back into academia. The global race to achieve high levels of AI, Data and Robotics deployment and the consequent economic gain will depend heavily on a well-founded and skilled workforce and on accessible, comprehensible tools that facilitate rapid uptake. These are driven by a coordinated and integrated AI, Data and Robotics research community that is jointly committed to developing excellence not only in AI, in Data or in Robotics but in collaboration; collaboration both with each other and with industry.

The following initial actions are envisaged:

1. Engage directly with the consortia managing the public AI, Data and Robotics infrastructure to work on strategic direction and issues, and with the Coordination and Support Actions that surround each AI, Data and Robotics asset.
2. Disseminate awareness of these resources within the broader eco-system and with partners in the Partnership.
3. To independently assess and strategically align the impact of the public AI, Data and Robotics infrastructure on the eco-system and its industrial uptake.

Engagement with EC Strategy

The rapid emergence of AI, Data and Robotics technologies has awakened the need for Europe and its member states to examine their strategy and policy towards their impact. From this has come a wide range of guidelines and official strategies that must be taken into account by the Partnership if it is to work across the whole European AI, Data and Robotics eco-system encompassing industry, member states, associations and academics.

There are many diverse perspectives on AI, Data and Robotics because of the wide spread of its potential impact and the fact that it must be treated as a Socio-Technical system which has ethical and societal dimensions. The Partnership must work to channel these different viewpoints so that deployment is acceptable and effective; acceptable to citizens and business and justifiable in the applications it is deployed in.

Work ongoing within the AI Alliance and the AI High Level Group to set out guidelines and strategic directions that respect multiple and diverse views on AI and the Partnership seeks to take their recommendations on-board as they are finalised and tested. Critical to this will be developing deployment strategies that can deliver against expectations that AI, Data and Robotics can be made trustworthy and comprehensible while at the same time making commercial sense.

Critical to EC policy on AI, Data and Robotics is the alignment with the individual actions of the member states. Alignment that creates a common AI, Data and Robotics market place across Europe, Alignment on standards of operation and ethical governance, alignment in public investment in AI, Data and Robotics infrastructures and research.

The following initial actions are envisaged:

1. To seek ways to implement and align the diverse strategies around European AI, Data and Robotics to generate a well-founded market for AI Data and Robotics in Europe.
2. To build long term partnerships and alliances with non-technical associations and bodies that are impacted by AI, Data and Robotics or have an interest in its deployment.
3. To examine and monitor the wider viewpoint of communities and special interest groups on the deployment of AI, Data and Robotics in Europe with the objective of creating an effective AI, Data and Robotics market in Europe.

BACKGROUND AND CONTEXT

The AI, Data and Robotics Partnership is one of the 46 candidate Public Private Partnerships in the upcoming Framework Programme[71]. The impetus for starting the preparatory work on this Partnership came by the European Commission, which adopted in 2018 the Coordinated Plan on Artificial Intelligence[72] announcing the intention to establish a Public Private Partnership on AI, in order to increase available financing for AI in Europe. The document called for private sector partners to commit high levels of investments and referred to the cooperation between BDVA and EuRobotics in this area as a basis to build on for the new Partnership. Following the adoption of this strategic document, BDVA and euRobotics signed a commitment to collaborate (Joint Vision Paper) and started working on the first version of the joint Strategic Research, Innovation and Deployment Agenda (SRIDA)[73], which was published in June 2019. A second version of the SRIDA[74] was released three months later (September 2019) and built on very close collaboration with the AI community and especially CLAIRE, ELLIS and EurAI.

About BDVA

The Big Data Value Association (BDVA) is an industry-driven international not–for-profit organisation with more than 220 members all over Europe and a well-balanced composition of large, small, and medium-sized industries as well as research and user organizations. BDVA is the private counterpart to the European Commission to implement the Big Data Value PPP program. BDVA and the Big Data Value PPP pursue a common shared vision of positioning Europe as the world leader in the creation of Big Data Value.

The mission of the BDVA is to develop the Innovation Ecosystem that will enable the data-driven digital transformation in Europe delivering maximum economic and societal benefit, and, achieving and sustaining Europe's leadership on Big Data Value creation and Artificial Intelligence.

BDVA enables existing regional multi-partner cooperation, to collaborate at European level through the provision of tools and know-how to support the co-creation, development and experimentation of pan-European data-driven applications and services, and know-how exchange.

About CLAIRE

CLAIRE was publicly launched on 18 June 2018 with a vision document signed by 600 senior researchers and key stakeholders in artificial intelligence, and the website, inviting stakeholders in artificial intelligence across Europe (and beyond) to sign their support. It has since attracted major media coverage in many European countries and garnered broad

71 https://ec.europa.eu/info/horizon-europe-next-research-and-innovation-framework-programme/european-partnerships-horizon-europe_en

72 Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic, and Social Committee and the Committee of the Regions - Coordinated Plan on Artificial Intelligence (COM(2018) 795 final), 7th December, 2018.

73 https://bdva.eu/sites/default/files/AI%20PPP%20SRIDA-Consultation%20Version-June%202019%20-%20Online%20version.pdf

74 https://bdva.eu/sites/default/files/AI%20PPP%20SRIDA-Second%20Consultation%20Release-September%202019%20-%20Online%20version.pdf

support by more than 1000 AI experts (PhD-level expertise in AI or equivalent), more than one hundred fellows of various scientific AI associations, many editors of scientific AI journals, national AI societies, top AI institutes and key stakeholders in industry and other organisations. Moreover, 10 members of EU High-Level Expert Group on Artificial Intelligence (HLG-AI) are also CLAIRE supporters. The CLAIRE movement works closely with the HLG-AI, providing them with the input of the European AI communities through various mechanisms.

In the initial months of CLAIRE's existence, Informal Advisory Groups (IAGs) in various field were formed, to provide a conduit between CLAIRE and the communities within AI (in both directions). Currently there are 9 IAGs, encompassing a total of 49 members. Each IAG focuses on a different topic, from Machine Learning, Knowledge Representation and Reasoning, Search and Optimisation, Planning, Multi-Agent Systems, Natural Language Processing to Robotics, Computer Vision and Ethics, Legal, Social Issues.

About ELLIS

The European Laboratory for Learning and Intelligent Systems (working title; abbreviated as "ELLIS") involves the very best AI European academics while working together closely with basic researchers from industry. The mission of ELLIS is to benefit Europe in two ways:

- By enabling the best basic research to be performed in Europe, allowing Europe to shape how machine learning and modern AI change the world, and
- By contributing to foster economic impact and create jobs in Europe, through outstanding and free basic research, independent of industry interests.

ELLIS will perform fundamental research in modern AI, attract top international industry research labs, and spawn startups that will become major players in the future. It will thus drive excellence in Europe's research and use of machine intelligence to foster economic development and improve the lives of people.

ELLIS will be a top employer in machine intelligence research, on par with Berkeley, Stanford, CMU, and MIT. It will also be a world class venue to get trained in the field: in conjunction with universities, it will develop a highly attractive European PhD program, and it will strive to retain the best graduates within ELLIS to groom them into the next generation of senior scientists.

About EurAI

The European Association for Artificial Intelligence EurAI (formerly ECCAI) was established in July 1982 as a representative body for the European Artificial Intelligence community. The primary aim of EurAI is to promote the study, research and application of Artificial Intelligence in Europe. Its members are the national AI associations of Europe from 29 countries and their individual members. Every even-numbered year, EurAI, jointly with one of the member associations of EurAI, organizes the European Conference on AI (ECAI). The EurAI Fellows program was established in 1999 to recognize individuals who have made significant, sustained contributions to the field of artificial intelligence (AI) in Europe. Fellows' accomplishments range from pioneering advances in the theory of AI, to unusual accomplishments in AI technology and applications. Usually only individuals who have made contributions to AI for a decade or more after receiving their Ph.D. (or are at an equivalent career stage) will be selected. The EurAI Fellows Program honors only a very small percentage of the total membership of all EurAI member societies (up to a maximum of 3%). Since 1998, EurAI has awarded the annual Artificial Intelligence Dissertation Award for the best AI PhD defended in Europe. Since 2012, and every two years since, EurAI has awarded a Distinguished Service Award to a European AI leader who has provided exemplary service to the European AI community.

About euRobotics

euRobotics is a Brussels-based international non-profit association that works to boost European robotics research, development and innovation and to foster a positive perception of robotics. The 250-plus members are research organisations, including universities, and commercial companies. euRobotics aims to strengthen the competitiveness of, and collaboration between, manufacturers, providers and users of robotics systems and services, and to ensure that robotics is adopted widely for professional and private use. Therefore, it aims at covering the full value chain from early-stage research to deployment. Four Prioritised Application Areas have been defined: Healthcare, Maintenance and Inspection of Infrastructure, Agri-Food, and Agile Production. In each of these areas, a network of Digital Innovation Hubs stimulate knowledge transfer and SME engagement. euRobotics uses its 27 Topic Groups (TGs) to involve a large community of different stakeholders in roadmapping and prioritisation activities. The TGs can be domain specific, cross-domain, technological, or non-technical.

euRobotics represents the private side of SPARC, the public-private partnership with the European Union to maintain and extend Europe’s leadership in civilian robotics. Its aim is to strategically position European robotics in the world, thereby securing major benefits for Europe’s economy and society at large.

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Process and Engagement of Deep Dives

AI Deep Dive

An initial draft of AI deep-dive section together with 16 questions was shared online mid-August as part of a broad community consultation. Member communities involved in the partnership, as well as other relevant stakeholder communities and networks, were invited through direct mail, community platforms and social media to engage with the preparation of the SRIDA by reading the draft and answering the questions. In total we estimate to have reached out to a public of about 20k - 50k stakeholders informing them about the orientation and scope of the partnership in AI, data and Robotics within a period of three weeks (17 aug 2020 - 6 sept 2020). We also received in total 196 responses from a broad range of stakeholders to our questionnaire including Large Industry (30), Start-up and SME (16) Academia (134), and Other (30), from over 20 countries (DE 32, ES 25, FR 23, NL 23, IT 11, UK 10, FI 10, NO 9, BE 9, PO 9 ,..). The respondents worked cross a broad spectrum of AI, including Sensing and Perception (95), Action and Interaction (109), Data, Knowledge and Learning (170), Reasoning and Decision Making (157), Systems, hardware, methods and tools (94), and there were also areas like Ethics (at large, 12 respondents), Human (6), Social/economical impact of AI (5) and natural language understanding (5). The received responses were clustered according to stakeholder category (Industry, Academia etc) to rebalance representativeness across stakeholder communities. The consolidated responses were then incorporated in the AI deep-dive as well as aligned to the overall text of the SRIDA.

Data Deep Dive

The engagement process of BDVA lasted three months and involved different activities.

July 2020 – Initial Data Collection and Stakeholder Engagement:

- BDVA organised two rounds of internal consultations based on a set of guiding questions to build the Data Deep Dive section, closing respectively on the 8th and the 24th of July. BDVA members and the BDV PPP projects could contribute to one or both rounds through two non-mutually exclusive options:
    1. They could share their views through BDVA Task Forces: the leads of the different Task Forces and Subgroups engaged the community and built a “community” response to the internal consultation, focusing in particular on the topics of relevance of the Task Force (i.e. specific application sectors, skills, data protection etc.). Through this channel BDVA obtained eleven aggregated Task Force responses. Within each Task Force, many different BDVA members participated in the discussions.
    2. They could submit direct member contributions and participate directly in the two Activity Group workshops organised (see below). BDVA received more than 20 individual members contributions for this third SRIDA version.

  At the end of the first round of consultation activities, an Activity Group workshop was organised on July 10th (AG37) to engage with the community and allow contributors (individual and Task Forces) to present their ideas. Around 50 experts participated in the discussions and several members and Task Force leads presented their contributions. Parallel sessions were organised to cover the different topics.

August 2020 - Consolidation

- During the month of August, the Data Deep Dive Editorial team started consolidating all input received in view of developing a first draft for discussion before the end of the month. This initial draft was the basis for the different activities carried out in September and especially the prioritization exercise.
- BDVA members and external stakeholders could still share individual contributions during this month.

September 2020 – Priorisation and Alignment

- An Activity Group workshop was organised by BDVA on September 7th (AG38). The purpose of this workshop was the identification of gaps, the prioritization of actions and the consolidation of contents in view of the final version of the Data Deep Dive. More than 70 experts attended the workshop and participated in the discussions.

Robotics Deep Dive

The Deep Dive Process for Robotics run from July to September 2020 and was organised in the following way:

- A first information and consultation workshop with the euRobotics Topic Group (TG) coordinators took place in in form of two online sessions on 23rd and 30th July 2020 to inform them about the process and to ask them to get engagement from their TG members.
- Based on that, the Robotics Deep Dive Editorial Team drafted an initial version of the Deep dive section during August 2020.
- In September 2020, this draft was given to the Topic Groups, where again an online session on 10th September took place. In addition the euRobotics Board of Directors was asked to provide further input.
- A final editing step concluded the process mid September 2020 by consolidating and reviewing all submissions and final content.

Engagement of wider Stakeholder Community

In parallel, BDVA, euRobotics organised two information sessions in order to reach the wider stakeholder community. Over 500 people engaged in the separate sessions which were organised in July on the 16th and the 29th.

An open public consultation for the SRIDA was launched in mid-July and remained open for the entire month of August. This open consultation:

- was presented during the information sessions in July.
- was not technology specific and covered all three technology domains (AI, Data and Robotics).
- aimed at gathering input from external stakeholders in particular other Partnerships;
- received around twenty full contributions.

In addition, we would also like to thank the BDVA office, in particular Ana Garcia Robles and Martina Barbero for their support in consolidating the third SRIDA release.

Contributions for SRIDA Version 1 and 2

We are very grateful to the 200+ participants at the 6 workshops by BDVA and euRobotics held in Feb-May 2019:

- BDVA workshop on 27th February 2019 (BDVA members and BDV PPP projects).
- Joint workshop on 20th March 2019 in Bucharest (public at ERF2019).
- euRobotics workshop on 11th April 2019 in Brussels (with BDVA participation).
- BDVA workshop on 30th April 2019 in Brussels (with euRobotics participation).
- euRobotics workshop on 8th May 2019 in Brussels (with BDVA participation).
- BDVA workshop on 16th May 2019 in Brussels (with euRobotics participation).

Additional workshops/events that contributed to the second version:

- “Joining forces to boost AI adoption in Europe” event, organised by BDVA and euRobotics on 6th June 2019 in Brussels.
- BDV PPP Summit on 26th - 28th June 2019 in Riga39.
- Bilateral online meetings with all the addressed communities.

We would also like to thank all additional contributions from members of the BDVA Task Forces and euRobotics Topic Groups.

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- EMVA: Dirk Berndt (Board member).
- Appointed representatives from 5G IA, AENEAS, ARTEMIS-IA, EPoSS, ETP4HPC and NESSI.
- Representatives from CLAIRE, EurAI, ELLIS and Humane AI.

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NOTES

ai-data-robotics-partnership.eu

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CLAIRE

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EurAi

eu ROBOTICS