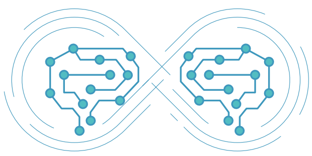
Artificial Intelligence Research Flanders

challenge-based research with **demand-driven** impact

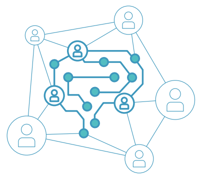
HELP TO **MAKE COMPLEX DECISIONS**

EXTRACT AND **PROCESS** INFORMATION AT THE **EDGE**

INTERACT AUTONOMOUSLY WITH OTHER **DECISION-MAKING** ENTITIES



COMMUNICATE AND **COLLABORATE SEAMLESSLY** WITH HUMANS



Summarizing the 4 challenges

Help to make complex decisions through data science

HELP TO **MAKE COMPLEX DECISIONS**

Decision makers for industrial processes and societal systems face an ever more daunting task. Every choice they make needs to be based on:

- knowledge and knowhow from experts such as doctors, engineers or market analysts;
- vast amounts of unstructured and structured data;
- numerous rules, guidelines and regulations on safety, ethics and privacy.

Luckily, future **decision support systems** will come to the rescue. To maximize their impact on the Flemish economy, we must make sure that they are:

- **automated** – By automating aspects of the data science process – such as raw data processing – we unlock its potential to all stakeholders, regardless of their technical data science skill level.
- **hybrid** – We need to unify the power of generated data with domain and expert knowledge. For example, by combining medical science with data from patient records, personal health monitoring sensors and clinical test targets.
- **actionable** – We have to turn data and knowledge into models that readily provide insights and inspire reliable decisions. These models must also give feedback to human experts, e.g. with interactive visual interfaces.
- **trustworthy** – All this has to be done with regard to the human in the loop and with respect for the data subjects' privacy and right to fair treatment.

Deliver artificial intelligence to the edge

EXTRACT AND **PROCESS** INFORMATION AT THE **EDGE**

Smartphones, drones, robots on the manufacturing floor, electric vehicles, ... Devices at the edge come with ever more performing and power-efficient AI processors. That enables them to take on **advanced edge computing and distributed machine learning** tasks, driven by three factors:

- increased real-time performance;
- enhanced power-efficiency;
- greater need for data security.

It gives rise to an entirely new set of AI use cases based on **intelligent, low-power (often battery-powered) devices**, as well as cases requiring on-the-spot, **real-time and secure decision support**.

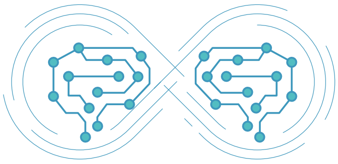
The challenge is to create:

- distributed and hierarchical AI systems;
- advanced signal processing;
- algorithms and technologies for extracting actionable information directly at the edge.

This move to the edge is **technically feasible and very relevant** for many use cases. Edge inference is forecasted to occupy about one third of the total market in 2023.

Interact autonomously with other decision-making entities

INTERACT AUTONOMOUSLY WITH OTHER **DECISION-MAKING** ENTITIES



Autonomous decision-making entities each have their own goals and intentions. In **multi-agent systems**, they need to interact with each other. Multi-agent systems are radically different from distributed systems. In multi-agent systems:

- No agent knows the whole system.
- No agent directly controls all the other agents.

Multi-agent systems can be anywhere on the spectrum between cooperative and competitive. And you'll find them in the real as well as the virtual world. Examples in the world of information are trading systems, routing systems and privacy-sensitive systems – where agents can't share certain information with each other. A lot of cyber-physical systems are also multi-agent. Think about smart power systems, traffic and fleet control systems and autonomous vehicles. All this poses a unique set of challenges.

Multi-agent systems need to:

- **adapt rapidly** to unpredictably changing environments;
- **adhere to constraints, rules and regulations**, even in the absence of central control;
- **be accountable and manageable** by their creators;
- **interact with humans**, by understanding their intentions and explaining their own behavior;
- **be open-ended**, so new agents, users and technologies can join at any time.

Communicate and collaborate seamlessly with humans

COMMUNICATE AND **COLLABORATE SEAMLESSLY** WITH HUMANS

Can an AI system really equal human performance when it comes to complex tasks? Or have we merely created good pattern matching techniques up to now? Many industrial applications need to go beyond such pattern matching.

They have to be **capable of complex reasoning** in a way that is autonomous, intelligent and trustworthy. This requires them to:

- communicate in ways that are effortless to humans, such as natural language;
- perform multi-step, human-like reasoning that entails perception and understanding of a complex environment.

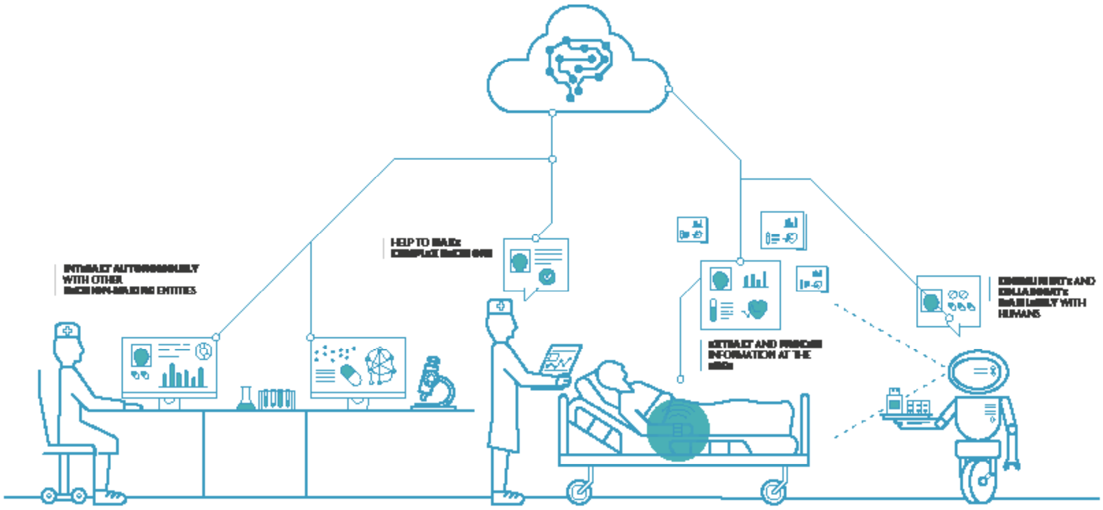
If we achieve this goal, we're able to enrich our society and workplaces with artificial entities that can identify and solve problems, **take on unseen tasks with the same agility as humans** – all while interpreting their social and physical environment and involving, informing and supporting their human colleagues.

Will we ever be able to equip technology with **real human intelligence**? Despite recent AI advancements, that goal is still far in the future.

We need systems that can **integrate and interpret, represent and understand their complex environment** in multiple styles and domains, over large timescales and in shared human-machine contexts. Therefore, we can identify two main objectives. Machines need to:

- seamlessly understand humans and interact with them;
- mirror the human capacities for learning, adapting, complex reasoning and decision-making across tasks, contexts & time.

Use case example:
Artificial Intelligence for efficient health care



Help to make complex decisions through data science

Do we want to deliver on the promise of **early disease detection, effective prevention and personalized therapies**? Then health professionals need access to decision support systems that allow them to exploit multi-level and real-time **health data** such as environment and lifestyle, and medical and molecular information. These systems must be:

- **hybrid** – The data of evidence-based medicine are combined with systems medicine and expert knowledge.
- **automated** – Raw data are automatically processed and unified with other knowledge sources. That allows non-experts to tackle more complex problems. With an exploratory approach, for example in genome analysis, they can detect unexpected new patterns.
- **actionable** – With predictive methods, medical professionals can improve preventive and therapeutic actions.
- **trustworthy** – Privacy and reliability of data are important concerns in a medical context. Medical staff, caregivers and patients need correct and transparent information that helps them to take the right actions and conscious decisions.

Soon, we will encounter these decision support systems in several medical subdomains: clinical treatment, drug discovery, patient monitoring, care automation, trend analysis, drug support, ...

Deliver artificial intelligence to the edge

There's a promising future for intelligent, low-powered AI devices in the medical sector. Particularly in two domains:

- **life sciences** – In field operations such as emergency care, there is often a need for **quick, accurate and cost-effective analysis** of substances such as blood. Imagine a typical requirement of being able to analyze 10 million DNA fragments within 60 minutes at a cost below € 300. This is only possible with highly intelligent, battery-powered cell-sorting and sequencing devices.
- **connected health** – Today, 24/7 patient monitoring is only possible with wired sensors within a hospital setting. If we want to switch to comfortable and low-cost **ambulant patient monitoring**, we need battery-powered, medical-grade and wireless sensors. These sensors need to operate at least 24 hours on one battery charge. And within a wearable and implantable health sensor network, they have to make collaborative health predictions such as risk at heart failure or septic shock.

Interact autonomously with other decision-making entities

In the pharmaceutical and medical sectors, data is often owned, explored and valorized by different entities. Huge strides forward could be achieved if these entities are **willing to share their data and models**, or to build new models cooperatively. Because of the sensitive nature of the (often patient-related) data, this must be implemented through **privacy-preserving cross-partner machine learning** that rules out unintentional leaks.

This will lead to a novel data economy model where contextual integrity relies on:

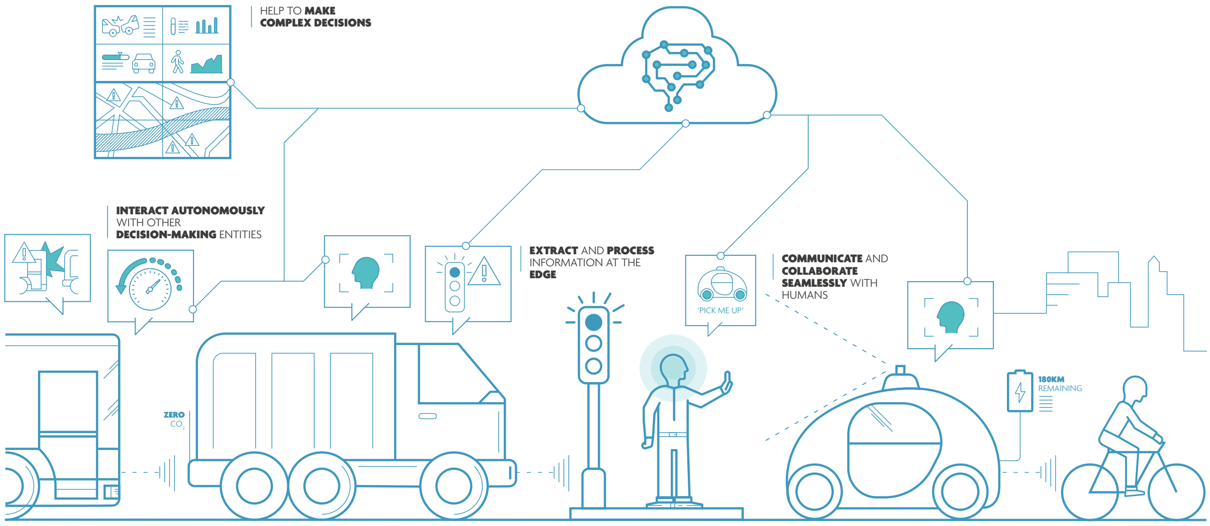
- **Compliance:** users of data need to follow rules and regulations based on beliefs and expectations.
- **Transparency:** in order to establish trust, citizens have to be able to see what happens to their data in the real world.
- **Contestability:** design and change rules must be based on user beliefs and expectations.

Communicate and collaborate seamlessly with humans

The healthcare sector is one of the sectors with a plethora of bottleneck jobs. Existing staff is often overburdened and recruiting skilled people is a huge challenge. Could AI **ease the workload of caregivers** by assisting them in social healthcare? Imagine AI systems that enable comfortable and independent assistant living, preventive care and rehabilitation. They do this by naturally interacting with their users and providing answers to complex problems. To make that happen, we need to focus on these **key research questions**:

- Can AI systems have **meaningful conversations** with patients? This should go beyond simple request-response interactions. AI systems need to interpret the human intention and behavior in open environments – including (non-)verbal aspects and situational contexts. If they succeed, AI-driven cognitive feedback loops can also prove useful in therapist trainings.
- Can AI systems **match therapists** in their interaction with patients? If they're confronted with a complex question, they should be able to provide a truly useful answer – thanks to their understanding of the user's explicit and implicit needs and intents, and of the environment.

Use case example: Artificial Intelligence addressing future mobility



Help to make complex decisions through data science

Mobility, transport and logistics are vital to our society. But they also come with considerable financial and environmental costs. Fortunately, huge **savings** are possible, thanks to decision support systems based on data science.

For example, by automatically integrating heterogeneous data streams with background knowledge, such as transportation schedules and physical network topologies, we can interconnect logistical networks to increase their total capacity and cut costs – the so-called **Physical Internet**. Or we could apply **hyper modeling approaches** for in-depth understanding of traffic situations, predictive route optimization, congestion root cause analysis or emergency response planning.

Local governments, who often lack data science skills, would also benefit from systems that automatically present them with understandable, actionable and policy-relevant information, based on the analysis of heterogeneous data concerning traffic, energy, crime, housing, etc. Naturally, such a truly **smart city** should always comply with ethical and privacy regulations.

Deliver artificial intelligence to the edge

Our mobility and logistics system is already undergoing a radical transformation towards **mobility-as-a-service**. It's based on electric, autonomous vehicles of different types that interact with each other and the environment through deterministic and adaptive communication means.

In order to ensure the reliability of these systems and the safety of all actors involved, **real-time inference and decision support** – without a detour through the cloud – is critical. And the individual subsystems and electronic control units should claim a minimal portion of the overall power budget.

Interact autonomously with other decision-making entities

Collaborative AI is an absolute prerequisite in situations where multi-agent teams need to realize a task together and, because of scale or communication constraints, central control is not an option. The best example is that of **connected cars** that need to 'negotiate' their joint use of the road infrastructure.

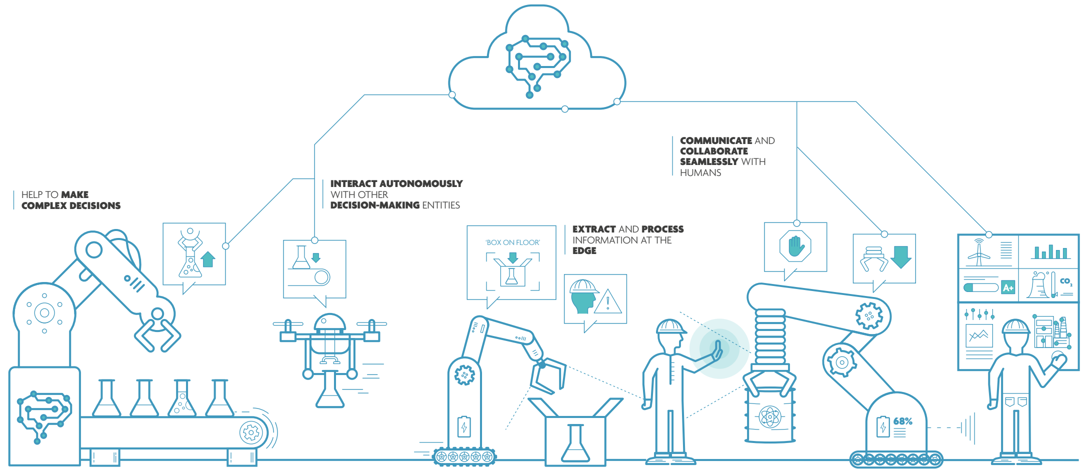
In some situations, such collaboration needs to take place within a competitive system. Autonomous agents, owned by different stakeholders, compete for resources or belong to a system with tight coupling constraints. In such cases **decentralized coordination** is needed to keep the system viable. A good example of this is a fair tolling system for road networks.

Communicate and collaborate seamlessly with humans

SAE levels 3 and 4 – **driver support in (semi-)autonomous vehicles** – already demand a high degree of natural human-vehicle interaction. We need technology that understands humans and interacts meaningfully with them, in a multitude of driving situations and perceived environments.

But for many, the ultimate goal of smart mobility is SAE level 5: full **autonomous driving** by a wide range of vehicles. And that requires an ever-higher degree of fast and complex human-like reasoning – including the ability to implicitly understand the intentions of other road users, which can be both human or AI-based. Truly autonomous vehicles need to react to completely unexpected situations with heterogeneous moving entities such as pedestrians, bicycles or animals. And they have to function in real open domain environments that may differ greatly from their previous experiences.

Use case example: Artificial Intelligence for Industry 4.0



Help to make complex decisions through data science

Today, our companies invest a lot of time in the design of complex physical systems. In **Industry 4.0**, active learning and AI-assisted data exploration will speed up those processes and make it cheaper to do simulations or experiments.

Operators, designers and plant managers can count on **hybrid analytics** to facilitate manufacturing processes such as real-time asset monitoring, process control and reliability management – often in the form of a **digital twin** of the factory. It's important that these actors have access to an overall AI-based system that they can trust and understand, and that helps them through automation and interactive guidance.

Deliver artificial intelligence to the edge

Our vision of the **factory of the future** is a floor filled with robots that are able to perform complex tasks like putting together an unfamiliar item on a conveyor belt in real time. Or a flexible assembly cell that consists of one or two mobots with 3D vision and sensing capabilities that drive around to pick up components and perform assembly operations – assisted by additional visual and cognitive sensors on the fixed infrastructure.

Science fiction? Not at all. But such **closed-loop robotic control systems** do require edge technologies such as high-resolution sensors (cameras, cognitive radars, LIDAR systems, ...) with proven low-latency processing.

Edge intelligence is also essential for **distributed predictive maintenance, condition monitoring and health awareness**. If high-frequency raw sensor data from a large number of machines and vehicles are processed locally, it reduces the need to communicate all the data to a central platform. That enables machine learning across a complex distributed network, where precise context-specific models are trained at lower levels and integrated and generalized at higher levels.

Finally, real-time and power-efficient edge technology is essential when machines and people work together. For instance, machines should be able to **continually measure and interpret the health and well-being** of operators, in order to optimize the operation speed and maintain general safety.

Interact autonomously with other decision-making entities

A **fleet** consists of interacting agents that are very similar but not identical – because they operate in other environments, are differently affected by wear and tear, etcetera. Such a fleet can consist of wireless networking nodes, hybrid vehicles, industrial machines, windmills, ...

AI systems can assist the management of such fleets by providing predictive maintenance. And if we go one step further, it should be possible to engineer a fleet to act as a body of autonomous decision-making entities that **jointly learn and optimize their performance**.

In some situations, various parties have their own goals but could benefit from cooperation. In such **a horizontal system**, real-time communication and collaboration lead to considerable optimizations.

Finally, in an **intelligent internet of intelligent things**, devices are able to take decisions on behalf of their users. In order for them to do this, they need to communicate with them, understand their goals and create a relationship of trust.

Communicate and collaborate seamlessly with humans

Will the factory of the future be a factory without humans? Not at all. On the contrary: AI will help **machines and humans to work together** in an industrial process that realizes the possibility of mass customization and personalization. We will encounter human-like AI in different forms:

- **operator support in the manufacturing industry** – Operators will work naturally and in real time with AI systems, thanks to speech recognition, sensors and visual aid through augmented or virtual reality. Of course, the AI systems have to be on a par with the humans in comprehension, interaction and complex reasoning. They need to know when to intervene, based on the operator's behavior, intent and cognitive load. And they have to offer humans complex and creative solutions by understanding problems and reflecting on them.
- **seamless human-machine interaction –** Cobots and humans will work together in dynamic environments. Within such mixed assembly cells, cobots need to understand human behavior, language and (implicit) intentions, flexibly interact and learn new skills. Also, they have to react fast to unforeseen human behavior or changes in the environment, to avoid obstructions and collisions.
- **complex control systems with minimal human input** – Humans should wholeheartedly entrust complex tasks to AI-enabled machinery. Ideally, they demonstrate or explain the task to the machine, which then fulfills it immediately and independently. Because of the trend towards mass customization, it's important that industrial machines are capable of quickly adapting to new tasks and even lifelong learning. More and more, the AI systems will be in the lead of operations, and humans will assist when needed.

And there's more

AI touches nearly every aspect of work and life.

Here are some other examples to stimulate the discussion.

Media and entertainment companies can rely on AI for assistance in the creative process (such as composition), talent scouting and sports game analysis. AI-based systems can also improve the quality and coverage of large product catalogues and their metadata, which would prove useful for recommendation and decision support systems for catalogue management.

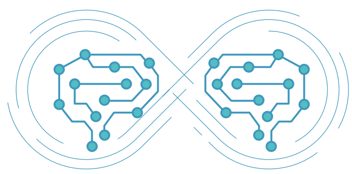
EXTRACT AND **PROCESS** INFORMATION AT THE **EDGE**

Social networking companies are under pressure to better monitor inappropriate and illegal content on their services – a task that is both time-consuming and distressing for humans. AI could certainly lighten that burden by assisting in the data exploration process.

Smart homes are occupied by robot companions that perform day-to-day tasks and interact naturally with their users. They are also able to delegate certain decisions to smart speakers and more advanced autonomous agents.

The utilities sector is already moving to a data-driven approach by relying on smart meters and sensors/actuators for the management of gas, water and electricity networks and supplies. More efficiency gains are possible by combining market behavior insights with accurate demand forecasts and real-time monitoring and control systems. AI methods are ideal for carrying out such complex tasks and will thereby facilitate decision-making.

INTERACT AUTONOMOUSLY WITH OTHER **DECISION-MAKING** ENTITIES



Precision farming could benefit from AI innovations to increase yields and reduce pollution. Examples include close cooperation between autonomous agricultural vehicles and drones with monitoring capabilities – such as hyperspectral cameras – for targeted seeding, harvesting and pest control.

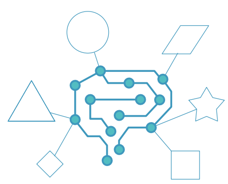
B2B and B2C companies invest a lot in customer relationship management, recommendation systems and personalization. They rely on hybrid approaches for combining customer behavior data with product graphs, ontologies, constraints, ... Automation is indispensable for training data models and frequently making complex decisions – with extra regard for privacy concerns.

Creative industries are looking at human-level intelligence to enrich systems for architecture and product design, narrative generation or content adaptation in journalism, entertainment and education.

COMMUNICATE AND **COLLABORATE SEAMLESSLY** WITH HUMANS

Biotech companies increasingly rely on high-throughput data to deepen their knowledge of biology. This complex and knowledge-intensive scientific process could benefit from a hybrid data science approach. If we develop techniques that are accessible to biologists who are not trained in data science, a new generation of life-changing scientific discoveries might be just around the corner.

HELP TO **MAKE COMPLEX DECISIONS**



Smart buildings react to the behavior of their inhabitants, by adjusting the heating, alerting a caregiver, locking the doors, ... To adequately consider the specifics of the environment and the situation, they need to learn from the historical data of sensors and understand the explicit preferences of their inhabitants. Conversely, these inhabitants need to understand the behavior of the AI.