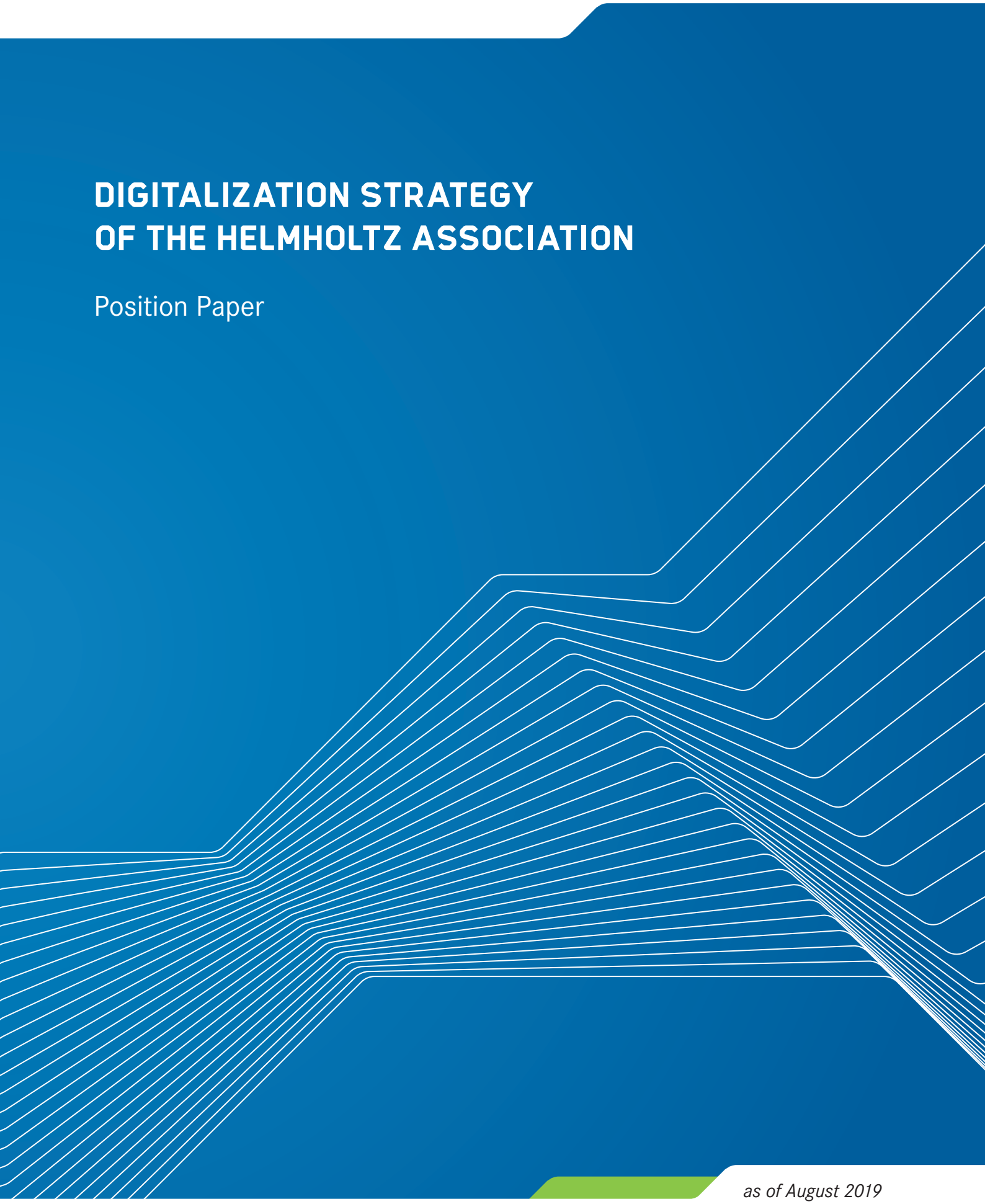
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DIGITALIZATION STRATEGY OF THE HELMHOLTZ ASSOCIATION

Position Paper



as of August 2019

CONTENT

Helmholtz contributes to solving the grand challenges facing society, science, and the economy by conducting top-level research as part of strategic programs within its six Research Fields.

We research highly complex systems using our large-scale facilities and scientific infrastructures, and cooperate closely with national and international partners.

Helmholtz attracts and promotes the best talents by offering them a unique scientific environment and ongoing support throughout every stage of their career.

We develop sustainable solutions for the future and cover the entire spectrum from basic to application-oriented research.

The Association comprises 19 scientific-technical and biological-medical Research Centers with more than 40,000 employees and an annual budget of more than 4.7 billion euros.

SECTION I – VISION AND GOALS

VISION

Digitalization presents enormous opportunities to overcome the challenges facing our society. The speed, scope, and systematic impact of the digital transformation surpass anything we have experienced before. This transformation is set to fundamentally change every part of our lives in the future – including how people will live and work, how they will receive healthcare, how the creation of commercial value will be structured, and how researchers will gain insights and develop new technologies.

Its strategically oriented, top-level research puts Helmholtz in an outstanding position that will enable it to continue shaping the digital transformation and help society reap the benefits of its opportunities even more effectively. The Association is perfectly equipped for this work because it produces an enormous amount of complex big data and uses large-scale research infrastructure to achieve a unique combination of research and development work focusing on both scientific findings and technologies. Helmholtz takes on three roles in this context:

1. As an initiator that helps to establish the methodological and technological basis for the digital transformation.
2. As an enabler that advances the widespread application of digital methods and technologies – and thus promotes top-level research.
3. As a stakeholder that utilizes new digital technologies in all of its research processes but also analyzes the impacts that digitalization and innovations have on social values and needs.

Serving as an initiator, enabler, and stakeholder in the digital transformation lets Helmholtz fulfill its mission and play a key role in solving the major challenges facing society at both the national and international levels. Helmholtz is aware that the digital transformation offers researchers opportunities to contribute solutions in a broad range of areas, including climate change, the energy system, mobility, widespread diseases, and feeding the world's growing population – and it is already exploiting these opportunities in diverse ways (► section II). As an organization, Helmholtz sets standards in the field of digitalization and uses the wealth of data at its disposal to continually generate new knowledge, thus giving the Association's top-level research a high profile at the international level.

With this in mind, Helmholtz focuses on six key questions:

How can all of the research fields benefit from digitalization as they work toward their goal of producing knowledge?
Helmholtz will use its top-level research to address large-scale, networked systems and infrastructures in an integrated way by means of new digital methods and processes.

What opportunities does digitalization present for producing data in the research context?
Helmholtz will digitalize and modernize its unique, large-scale facilities, instruments, and platforms on an ongoing basis. It will use this approach to continue developing its methods of generating and collecting data and exploit previously untapped potential.

What does digitalization mean for the research process?
Helmholtz aims to act as a pioneer in both its own research and external use, and to usher in a new era by establishing innovative information infrastructures for a vast range of data products and services. Based on a coordinated management system for its research data, the Association generates complex datasets in all of its departments and provides access to this data. It has a unique opportunity to establish large-scale infrastructures that will benefit Helmholtz as a whole. The resulting economies of scale set it apart from any other research organization in Europe.

What technologies are necessary to conduct research in the future?
Helmholtz is a driver of digitalization. As such, it aims to deliver both enhanced and completely new information and communication technologies. Together with new digital methods, these technologies will transform data into insights in a secure, efficient, scalable, flexible, and pioneering way. Knowledge and planning processes of a completely new quality will be established in science as a result.

What talents will be required for research in the context of digitalization?
The Helmholtz Centers are convinced that data expertise will be a key skill for researchers in the future. To this end, it will train and recruit a new generation of data experts who possess in-depth expertise pertaining to both information technologies and the interfaces to other scientific domains.

What does digitalization mean for Helmholtz as Germany's largest research organization?
Helmholtz addresses the challenges of the digital era, actively shapes the transfer at its Centers and within the Association, and promotes the translation of technologies and knowledge into innovative applications and ways of creating value. However, it is also accountable for using its expertise and experience to help shape public opinion and structure the parameters of digitalization. In this way, the incredible driving force of the digital transformation will yield benefits and value for people and will be accepted by society.

GOALS

Helmholtz has outlined ten goals that serve as the basis for its digitalization strategy and will enable it to successfully implement its vision:

1. To use digital methods and technologies to research complex systems
2. To research smart and secure technological systems
3. To digitalize research infrastructures at Helmholtz
4. To provide overarching, sustainable information infrastructures
5. To promote and strengthen research through the use of digital tools
6. To research and develop the next generation of information technologies
7. To serve as a hub and magnet for scientists
8. To master national and international digital challenges through the transfer of knowledge and technology
9. To shape the digital transformation in science and administration at Helmholtz: digital cultural change
10. To conduct digitalized research on behalf of society

1. To use digital methods and technologies to research complex systems

Complex systems are part of our everyday lives, including transport systems, urban environments, the energy supply, information systems, industrial value chains, the healthcare system, the planet Earth, the economy and social systems, and ultimately human beings themselves. Helmholtz aims to arrive at a fundamental understanding of the way these systems function and dysfunction. This will make it possible to explain and predict their formation and development and address their weaknesses. A wide range of components need to be analyzed to come to this understanding, and the functions of these components interact with one another in a complicated array of dynamically changing connections on varying scales. In this context, digital methods and technologies open up new points of access that lead to more in-depth insights and findings regarding system characteristics that benefit science and society. An approach that upholds ethical principles – particularly in terms of handling information securely and protecting personal data – is of paramount importance here.
Helmholtz uses digital methods and processes in every area of its top-level research. These are combined with innovative, application-oriented approaches from the fields of information technology, mathematics, and systems science. Based on this approach, data can yield new knowledge, which forms the basis for an understanding of natural and technical systems. The resulting models serve as dynamic digital maps that support processes for making decisions and taking action in the analysis and synthesis of systems.

2. To research smart and secure technological systems

Thanks to the new opportunities offered by digitalization, technological systems and infrastructures are developing differently and more rapidly than before. Prime examples include the energy system (including sector coupling), the design and networking of mobility systems, the structures used to provide healthcare, and the research infrastructures themselves. These smart technological systems and infrastructures will enable interactions at new levels in the future – between the systems and infrastructures themselves, with their environment, and in the course of interactions with humans. The systems operate as part of a network to a high degree, are integrated into larger groups, and are capable of organizing themselves independently. This results in completely new challenges with respect to their agility and our ability to use them securely. These factors are largely determined by the system design and in particular by the performance of sensors and actuators as well as by regulation and control systems. Human-machine interfaces and the basic technologies they require are essential for observing and monitoring systems as well as operating them effectively.
Helmholtz is addressing these new challenges in the course of its research and development by focusing on both knowledge and solutions. Security, data protection, and privacy are viewed as integral aspects in this context. New findings and technologies are reflected in socioeconomic and ethical terms.

3. To digitalize research infrastructures at Helmholtz

The speed at which data is being recorded, its increasing scope, and the heterogeneity of the collected data mean that the research infrastructure at Helmholtz needs to be used in an even more effective way. This requires advanced tools and digital approaches for collecting, storing, archiving, publishing, analyzing, and annotating data as well as tracking its provenance. Data should be managed and the corresponding analysis performed in real time for high volumes and rates of data. Technologies for reducing and compressing data are key factors in achieving this. Metadata supplements the recorded data so the experiments and observations can be described, tracked, and reproduced. Work processes need to be transparently designed and backed up by quality controls when they are carried out. This ensures that the data is traceable and reproducible from its point of origin up to the derived scientific findings.
Helmholtz will continue to generate digital twins of research infrastructures, which record all vital characteristics and functions and provide a digital backup for the facilities. This makes it possible to simulate the way the respective research infrastructure will be used in advance. Doing so can make it easier to plan logistics, control the measurement process, monitor and maintain instruments, and evaluate the recorded data more precisely at a higher resolution. The functionality of existing instruments can be improved and new instruments developed. Last but not least, the analyzed systems can and must be integrated into subsequent models to facilitate a comprehensive understanding of the measurement process. As a result, the performance and efficiency of the research infrastructure can be continually enhanced; the quality of the measurements and the evaluation of the generated data are also improved. In doing so, Helmholtz focuses on and participates in the development of national and international standards and strategies.

4. To provide overarching, sustainable information infrastructures

Helmholtz establishes coordinated information infrastructures that can be used over the long term – both for its own research as well as for external use. This fosters close networks between researchers and allows them to expand and deepen their collaboration.
Helmholtz provides systems that serve as the technological basis for the information infrastructures and enable data-intensive supercomputing up to the highest performance class. These information infrastructures are implemented on a decentralized basis and networked with one another. They are made available to both internal and external users for tasks such as data analysis, machine learning, and simulations based on selection criteria that are as uniform as possible.
Research data and information that can be used within and beyond the field of science are provided in the information infrastructures. The experimental and observed data occur in a variety of formats and come from various sources ranging from particle accelerators to the sensor of a research vessel. In order to be able to work with these datasets, they need to be harmonized, aggregated, and integrated. It is also necessary to use a standardized approach to record metadata that documents all of the steps involved in data processing along with the software tools used and their parameter settings.
Helmholtz provides software that can be combined in a modular way in its information structures and beyond so data products and services can be used rapidly and effectively. Software is seen as part of the strategic infrastructure that can be used to transform data into knowledge. Helmholtz thus uses an Open Science approach to promote the long-term development, distribution, and support of the software. Therefore, the range of services provided by the information infrastructure includes data products, scientific software for data analysis and simulation, modeling and simulation systems for fundamental questions in the various scientific communities, sample case studies, and demos.
Based on its expertise, Helmholtz will serve as a powerful partner to the German Research Data Infrastructure (NFDI) and the European Open Science Cloud (EOSC) and promote the development of effective, open, and sustainably financed infrastructure.

5. To promote and strengthen research through the use of digital tools

New digital methods and tools support scientific research. They make it possible to redesign the processes used to generate knowledge itself. The use of powerful research and information infrastructures strengthens the capacity of top-level research to work across all scales and in multiple dimensions in a systems- and solution-oriented way. This top-level research is conducted across Centers and research fields in the course of interdisciplinary collaboration between researchers who focus on basic findings, methods, or technologies in their work. This leads to new research approaches at the interfaces between existing research fields – and therefore to new knowledge and findings.

Helmholtz will (further) develop scalable algorithms that can be used on a comprehensive basis and make these available in the form of easy-to-use Open Source Software libraries for the purposes of data recording, data management and analysis, for modeling, simulation, and optimization, and for artificial intelligence and machine learning. These algorithms are developed as modular, reusable, and open solutions and established according to international standards.

All of these digital methods and tools are aligned with researchers' needs as well as the administrative and technical support roles, and launched in close cooperation with them. The research fields will determine corresponding strategies for their coordinated implementation. Topic-based hubs will give the research fields the opportunity to regularly discuss key aspects relating to the digitalization of the research processes, methods, tools, and information technologies, and to determine general needs. The research field hubs, in turn, will form a network that extends across the research fields. This will make it possible to create Helmholtz-wide synergies; define common standards; and achieve a critical mass for developing technologically strong information infrastructures for research purposes.

6. To research and develop the next generation of information technologies

Helmholtz contributes its wide-ranging expertise to the development of future information technologies. This is because the digital transformation as a whole as well as the observation, analysis, and synthesis of complex natural and technical systems on their own will only be successful if information technologies continue to develop. Usability, performance, energy efficiency, and security are the key target dimensions that are to be observed in this context. Combining principles and theories of information processing, material and systems science fundamentals, component and system design, as well as application and user platforms as part of a holistic approach will make it possible to successfully address these dimensions.

The rapidly increasing requirements call for disruptive developments that can overcome the increasingly apparent, inherent limitations of the technologies available today. They call for new insights into the scientific principles of information processing, particularly material physics and material chemistry, but also into biological systems, especially into the human brain. Quantum technologies and neuro-inspired technologies point to innovations that will lead to the development of computers offering undreamed-of gains in performance and efficiency. These simultaneously serve as the prerequisite for higher data and computing capacities as well as for their rollout in autonomous systems in every area of technology. In addition, new systems and architecture approaches for computing and the needs-based storage of large-scale data are required to achieve the target dimensions of usability, performance, energy efficiency, and security.

7. To serve as a hub and magnet for scientists

Helmholtz will help to train the new generation of digital natives to ensure that it and the Association's six research fields can continue to play a key role in finding solutions to global challenges in the future as well. At the same time, this will boost the attractiveness of Helmholtz as a magnet for top talent from around the world. A key instrument in these efforts is the Helmholtz Information & Data Science Academy (HIDA), which Helmholtz has launched in cooperation with partner universities (► section II). In structural terms, its development is being driven by closely linked regional Helmholtz Information & Data Science Schools (HIDSS), and it serves as a central training and further education site for young and established researchers alike as regards its content. Helmholtz professors also support digital talents by teaching at universities.

In addition, steps must be taken to enhance all employees' capacity to work with digital technologies. To this end, Helmholtz provides opportunities for training and further education and also makes learning platforms and suitable digital media available. The tools, infrastructures, and processes that will be introduced when the Helmholtz Digitalization Strategy is implemented form the core of these efforts.

Helmholtz needs international researchers at every stage in their careers who conduct research on an interdisciplinary basis and possess relevant qualifications at the interfaces to the data and simulation sciences. They work together in interdisciplinary teams and understand the specialist language of the participating fields. New, sustainable career paths are created for experts from the fields of IT, mathematics, and data and simulation sciences. The goal is to make Helmholtz an internationally attractive employer so it can recruit young scientists with relevant expertise in digital technologies and their application, and retain top scientists over the long term. The Association's visibility in international projects, standardization committees, and the open source community will contribute to enhancing its attractiveness.

8. To master national and international digital challenges through the transfer of knowledge and technology

The transfer of knowledge and technology is a key instrument for making scientific findings available to society. Innovative formats for collaborations, communication, and new cultures both within and beyond Helmholtz are to be promoted as part of the digital transformation.
Established instruments such as patenting and licensing as well as startup programs will be used to tap into the commercial benefit of the potentials offered by innovative hardware. Common standards and approaches for action will be developed in order to make software and software-based services available to commercial users.
However, a strategically designed approach to transferring knowledge covers much more than utilizing the findings for purely commercial purposes. Helmholtz is an active partner of Open Science communities around the world and a pioneer when it comes to the open exchange of data, data products, and software, as well as software-based solutions and the active involvement of society and industry in the scientific process. The information infrastructure services provided by Helmholtz follow coordinated Open Science principles and standards that are pursued and further developed on an ongoing basis: Open Access, Open Source, and Open Data, which follow the FAIR data principles (findable, accessible, interoperable, reusable).

9. To shape the digital transformation in science and administration at Helmholtz: digital cultural change

The digital transformation is fundamentally changing the world of work and necessitating adjustments in the education and training system as well as in corporate cultures. In the midst of this cultural change, Helmholtz wants to establish a stronger role for itself as a digital designer, support globally applied standards, methods, and new technologies, and play a role in furthering their development.
The digital transformation comprises all research processes and the associated administrative and technical support processes. In order to shape this (cultural) change, Helmholtz aims to make the opportunities that digitalization offers tangible at the level of the Centers and the Association. It will promote the consistent implementation of new digital working methods by the scientific and administrative levels of the Association and help these methods to become second nature in every area at Helmholtz. These processes will consistently take data security aspects into account in their design. This will require common principles for their governance and a balance between cooperation and competition on a shared basis.
The technical standards that have been established throughout the entire Helmholtz Association are a further success factor for the widespread use of digital tools. At the administrative level, the key focal points are (partial) automation as well as supporting and optimizing business processes. In the scientific area, the focus is on what is known as interoperability – innovations need to be generic, transferable, and suitable for common usage if they are to effectively support research.

A high level of recognition and appreciation must be demonstrated to employees who work in an administrative or technical/scientific capacity, in data management, or in software and technological development, thereby enable world-class research; furthermore, appropriate career paths must be made available to these employees. Helmholtz will promote a culture that not only recognizes scientific achievements – which are measured by the quantity and scope of publications – but also other digital outcomes, regardless of the form they take.

10. To conduct digitalized research on behalf of society

Research pertaining to the digital transformation has an effect on our entire society. Helmholtz sees it as its duty to respond to these societal effects, and the key figures in this context are always human beings, who act as self-determined agents. For this reason, Helmholtz takes ethical and legal implications into consideration in its work. These implications are the result of new global interconnectedness, new processes and forms of collaboration, the innovative use and analysis of data, networked mobility, or new value structures, for example. Helmholtz wants to address these aspects in all of its research fields, because new opportunities to shape digitalization are arising in numerous research areas – including research into mobility, the environment, and healthcare. A considered approach must be used to integrate these areas into society, politics, and business.

To this end, Helmholtz will devote more effort to technological impact assessments as well as responsible research and innovations relating to the opportunities and risks posed by digitalization. Options for action and design that take ecological, economic, ethical, social, and legal aspects into account in a balanced way will be developed. These aspects must be taken into consideration from the very start in keeping with the Association's sustainability principles.

Digitalization is having a multifaceted impact at the national and international levels. On the one hand, it is simplifying globalization and promoting the development of new collaborations and networks. On the other hand, stakeholders are interacting with one another in new and different ways around the world. This makes it necessary to establish new common rules regarding standardization and unification, such as responsible methods for dealing with patient data. Both aspects need to be considered and addressed in equal measure in the context of digitalized research.

For Helmholtz, socially responsible research ultimately means organizing its work in a sustainable manner that protects the environment and saves resources. This applies equally to the areas of management, research, infrastructures, human resources, and support processes. Helmholtz wants to use digitalization to actually surpass its past achievements in all of these areas.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SECTION II – ONGOING ACTIVITIES

As an organization that devotes its research to the major challenges currently facing society, Helmholtz has acquired vast skill sets in areas directly related to digitalization in recent decades. These include information processing, big data, data analytics, simulation, modeling, bioinformatics, imaging techniques, research data management, supercomputers, robotics, technical and biological information systems, and many other technologies. Helmholtz has at its disposal a wealth of data that is growing exponentially and is almost unparalleled at any other research organization – and it uses this data to yield new knowledge on a continual basis.

The Centers and research fields at Helmholtz are also at an excellent position to form successful, synergetic connections between their various competencies: They function as developers and operators of large-scale research infrastructure and latest generation supercomputers, and represent centers of expertise for complex simulations. This also means that they have long been familiar with the entire data life cycle, including research planning and the collection, quality control, documentation, publication, archiving, integration, analysis, and utilization of very large and complex volumes of data. World-leading approaches and outstanding methodological expertise can be found in the respective subareas at all Helmholtz sites and across them.

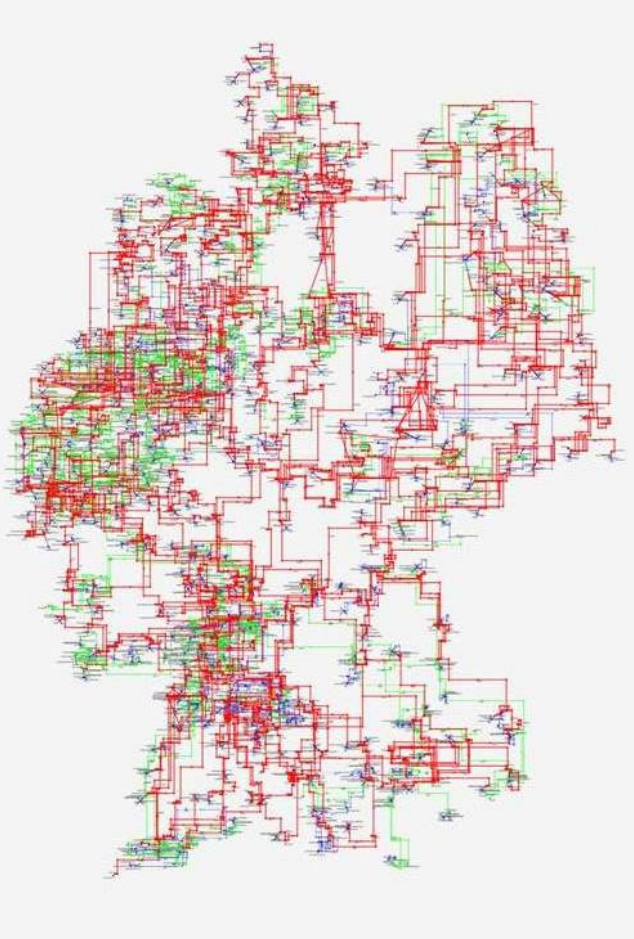
A wide range of activities that form important building blocks for achieving the Association's digitalization goals have been initiated on this basis in recent years. A few examples of these activities are described below.

RESEARCH FIELD ENERGY

Infrastructures for future energy systems – coupling technology and big data in a smart way

Future energy systems will be characterized by a wide range of distributed renewable energy facilities and close networking. These types of complex energy systems can only operate to best effect if the process of digitalization and automation continues to advance. However, a fully automated energy system will require new control room concepts and technologies like those being developed for the Energy Lab 2.0 energy research infrastructure. One promising solution for full automation is using a multi-agent approach to plan resources for the controllable components involved in the system. These include, for example, units that both produce and consume energy (prosumers), cogeneration plants, and battery storage systems.

The production of electricity from renewable sources of energy is not freely controllable due to their so-called intrinsic volatility, for example the availability of wind or sunlight. For this reason, big data-driven, probability-based forecasts for the output and energy production of renewable energy plants will be used for resource planning.



RESEARCH FIELD EARTH AND ENVIRONMENT

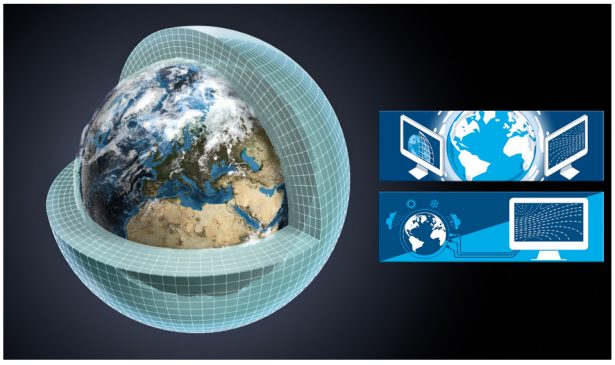
Helmholtz Earth – integrating observation and modeling in Earth systems research via data sciences and artificial intelligence

The foundation for Helmholtz Earth consists of comprehensive research data management and the associated service infrastructures, which are designed to transcend the boundaries between projects, research fields, and Centers. Helmholtz Earth is based on a joint program called The Changing Earth – Sustaining our Future.

The methodological knowledge and datasets can be made available to the data sciences as well as those involved in modeling in concerted form as part of an integrated data hub (ATMO, MARE, TERRA). This data hub is based on the initiatives and platforms of the ► Helmholtz Incubator. It takes into account the existing initiatives that have strong links to the digitalization strategy in the research field, such as Digital Earth and Advanced Earth System Modeling Capacity. Observation infrastructures (such as MOSES and remote sensing platforms) play an important role in creating flexible ways to make data available through the data hub. It is embedded at the national and international levels via the German Research Data Infrastructure and the European Open Science Cloud (EOSC).

Making observation and modeling data readily available across projects, areas, and Centers enables researchers to test the latest knowledge discovery approaches. The research field Earth and Environment will thus become a catalyst for interdisciplinary and transdisciplinary work beyond the research field by serving as a virtual research environment. The research field's key principles are Open Science and FAIR data for Earth systems research as well as orchestrating the digital transformation of the value chain, from services for research all the way to society. Synergies within Helmholtz will be exploited in both the national and international environment.

The research field's achievements and involvement in international beacons of excellence in the field of digitalization will also come into play in EU projects and other international partnerships. Its main methodological focal points range from modeling, using digital methods to organize large observatories and their data, and implementing the FAIR principles, to harmonized analyses of available observation data for global data products. Prominent examples include: EIDA (European Integrated Data Archive within the European Plate Observing System EPOS), IQOE (International Quiet Ocean Project), ARGO (The international ARGO Project), JERICO-Next (Joint European Research Infrastructure for Coastal Observation), SOCAT (Surface Ocean CO2 Atlas), NDACC (Network for the Detection of Atmospheric Composition Change), and CMIP6 (Climate Model Intercomparison Project 6 for the IPCC). In this way, Helmholtz makes an important contribution to both international global change research as well as efforts to implement Open Science.



RESEARCH FIELD HEALTH

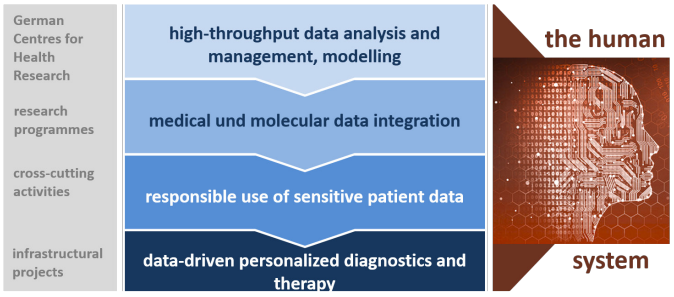
From the “human system” to personalized medicine

Digitalization offers tremendous opportunities for linking and analyzing data in the field of health research. The Helmholtz Centers have been working across the Association for many years to develop and utilize complex and dynamic datasets as well as patient data that are frequently heterogeneous and still incomplete. As a result, they have amassed extensive expertise in the area of high-throughput data management, analysis, and modeling. This expertise extends from basic biomedical research on decoding disease processes at the molecular level to the routine use of molecular high-throughput technologies and medical imaging. Together with clinical data, these technologies are increasingly being used for data-driven personalized diagnostics and treatment.

In the future, the research field Health will pool expertise extending across indications on an even more intensive basis with the goal of integrating medical and molecular data to yield a better understanding of the “human system.” To this end, it has created visionary structures that focus explicitly on digitalization, which enables synergies and pools competencies. Examples include the Berlin Institute for Medical Systems Biology (BIMSB), the Braunschweig Integrated Centre of Systems Biology (BRICS), the Centre for individualised infection Medicine (CiiM) in Hanover, and the Heidelberg X-Ten platform for whole genome sequencing. Training concepts will be implemented, for example within the scope of the Helmholtz Pioneer Campus, so the acquired expertise can be maintained and enhanced. The research field Health has already been developing novel concepts under these conditions for many years in the areas of federated computing, modular supercomputing, memory-driven computing, IT infrastructure (such as the HiGHmed technology platform), artificial intelligence, machine learning, simulation, and mathematical modeling. Moreover, automated evaluation methods for processing multimodal image data from (pre)clinical studies and their translation into clinical routine have been developed, for example, and new smartphone-based concepts such as the Surveillance Outbreak Response Management and Analysis System (SORMAS) for rapidly recording infections on an individual basis have been established.

The research field’s scientists take the lead in international initiatives such as Human Cell Atlas, Critical Assessment of Metagenome Interpretation (CAMI), Pan-Cancer Analysis of Whole Genomes (PCAWG), and the LifeTime Initiative.

It is also worth highlighting the leading role the health centers play in dealing with personal data. The security of patient data comes with special ethical responsibilities and is subject to strict legal regulations. The health centers involved in the Helmholtz Medical Security, Privacy, and AI Research Center (HMSP) address these issues together with the Helmholtz Center for Information Security.In this way, the research field Health will utilize the opportunities that digitalization offers to achieve new breakthroughs in medical research.



RESEARCH FIELD INFORMATION (KEY TECHNOLOGIES)

Methods and models for data and simulation-drive research

Innovative and interdisciplinary cooperation, new developments in areas relating to the processing of digital information, complex simulations, and the analysis of complex data result in the potential to gain new insights in data and simulation-driven sciences. Simulation models up to the highest performance class are scaled and innovative data management methods are researched and developed at simulation and data life cycle labs in the Supercomputing and Big Data program as part of interdisciplinary and application-oriented joint research and development work. These sim and data labs are supplemented by methodological, technology-based teams who work across disciplines, and selected research groups in pilot areas such as quantum computing, performance engineering, federated computing, exascale numerics, and machine learning.

This has made it possible to achieve impressive results in fields of application including the neurosciences, materials research, climate research, and energy research. For example, high-performance and supercomputing methods have been combined with data science and software engineering for the field of materials research in order to develop new, scalable environments based on workflows and adaptive, block-structured meshes. These are used to simulate application scenarios in the highest requirements class, for example in virtual material design, on the most powerful supercomputers.

In the neurosciences, new models have been developed together with IT specialists so cerebral functions can be simulated across all scales – from morphological cells to the entire brain. In order to be able to run simulations at an appropriate performance level up to the exascale, new domain-specific terminologies and modular, interactive workflow environments are a component of current research; this includes the fusion of data from simulations (large model calculations) and experiments (cohort studies).

Scientists in this research field take top-level roles in the scientific leadership of two out of three European Flagship Projects, the Human Brain Project and the Quantum Technologies Flagship.

RESEARCH FIELD AERONAUTICS, SPACE, AND TRANSPORT

Achieving a high degree of automation and networking diverse systems

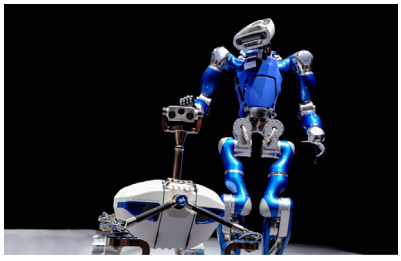
Automation and networking offer significant advantages and are becoming established in many fields of application.

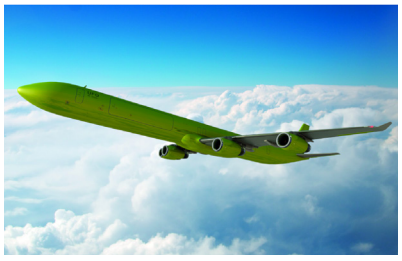
Robotic systems support people in numerous applications and are intended to execute tasks related to mobility and interactions with the environment as autonomously as possible – in the fields of space, production, medical technology, and care. They make it possible for people to interact with their environments effectively, efficiently, and safely. One of the central aspects in this context is interactions between people and robots, which take place at both the physical and cognitive levels. A further key research objective is to impart a knowledge of their own capabilities to robots. Innovative and flexible production chains are being developed in the Factory of the Future project; these chains extend from the digital model to a reconfigurable factory with custom products that are manufactured using automated processes.

Unmanned aircrafts will play an increasingly prominent role. The path from today's two-person cockpit to a remotely piloted cargo aircraft is mapped out and will pass through the intermediate stages of single-person cockpits, optionally piloted vehicles (OPV), and remotely piloted aircraft systems (RPAS). Aircraft systems for the unmanned transport of cargo and their integration into the existing air space are therefore a further focal area for research. The aircraft system also comprises the required infrastructure, particularly the control station as well as satellite-based data connections and systems for determining the aircraft's position.

In the future, transport on land will also be highly automated, interlinked, resilient, and cooperative, and will span domains. The question of the acceptance of highly automated systems will be addressed by testing new methods of traffic management as well as highly automated, networked vehicles – in both simulations and real-world situations. Developing a smart traffic management system is a further goal. This will include a precise, three-dimensional digital image of traffic routes in order to enable highly automated vehicles to cross-check the environmental data generated by sensors and make these systems safer.

Its combined efforts in the fields of aeronautics, space, and transport research make this research field one of the front-runners in the development of highly automated and networked systems.

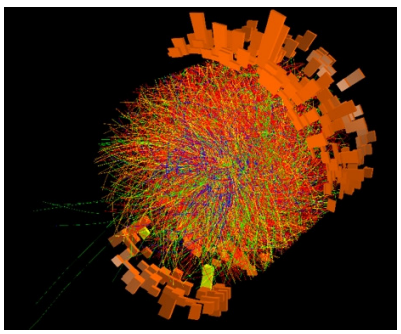
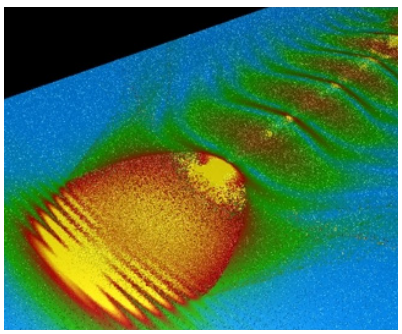
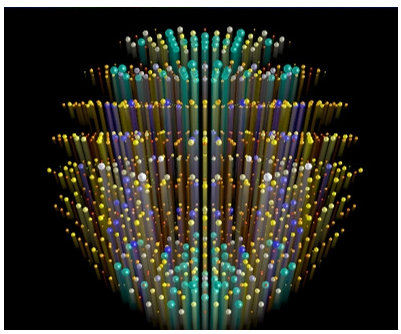




RESEARCH FIELD MATTER

Analyzing complex systems and complex data

The research field Matter and its numerous large-scale research facilities has been a pioneer in efforts to digitalize research and approaches for dealing with large volumes of data for decades. This applies to the rapid collection and filtering of data as well as complex data analyses involving the latest available methods and data archiving. Key examples include extensive software developments for managing data such as the dCache data management system or the LCIO detector simulation software, analysis packages like FAIRoot or the ALPAKA analysis software stack, which is a software stack for the uniform programming of heterogeneous multiprocessor systems. Comprehensive simulations in Lattice QCD or plasma simulation, such as PIConGPU and FBPIC, are already among the typical tools that researchers use, along with the sophisticated analysis of millions of pieces of sensor data from accelerators.
Comprehensive analysis infrastructures are operated and enhanced in the research field Matter today. Data volumes extending to 100 petabytes per year place significant demands on the digital infrastructure of the Centers and require close coordination with those who operate the research equipment. Firstly, this pertains to the TIER supercomputing centers, which primarily support experiments at the Large Hadron Collider (LHC), the world's largest particle accelerator. These centers are incorporated into the Worldwide LHC Computing Grid (WLCG) collaboration. Secondly, it involves directly linking the experiments at the Centers, such as the PETRA III X-ray microscope, the ELBE radiation source, and the European XFEL laser.
If the challenges presented by digitalization are addressed successfully, science will be able to investigate and comprehend the structure and dynamics of complex systems at an unprecedented spatial and temporal resolution in the future. This will be possible thanks to the next generation of large-scale facilities and observatories, such as PETRA IV, BESSY VSR, BESSY III, FAIR, ESS, CTA, HL-LHC, and DALI. The research field set up the topic of Data Management and Analysis in the Matter & Technology program in order to establish the partnerships required for this purpose at the institutional level.

HELMHOLTZ INFORMATION AND DATA SCIENCE INCUBATOR

The Helmholtz Association founded the Helmholtz Information and Data Science Incubator in 2016 with the aim of merging and expanding its incredible expertise and the enormous quantities of data at its disposal. The Incubator brings together researchers from all of the Centers, supported by experts from research companies. By founding the Incubator, Helmholtz is pursuing the goal of fostering regular interactions between creative minds from throughout the entire Association, creating a foundation for innovative, interdisciplinary networks and approaches, as well as identifying pioneering topic areas and disruptive pilot projects. The experts involved in the Incubator also plan and support long-term value adding activities and platforms, and flesh out the Helmholtz Digitalization Strategy.

Information and data science pilot projects

The Incubator aims to boost information and data-based research at Helmholtz by serving as a catalyst for the development of pioneering projects that transcend the traditional boundaries between disciplines and research fields.

For example, the Helmholtz Analytics Framework pilot project pursues the systematic development of domain-specific data analysis techniques as part of a co-design approach. Participants in this process include domain scientists as well as IT specialists. This creates potential for scientific breakthroughs and new findings in demanding application scenarios such as Earth systems modeling, structural biology, aerospace, medical imaging techniques, and the neurosciences. Ultimately, the aim is to generalize and standardize the researchers' work based on an exchange of methods between individual scientific areas. The Helmholtz Analytics Framework works closely with the previously established Helmholtz Data Federation (HDF), a federated research data infrastructure using the latest data storage and analysis hardware.

Information and data science platforms

The Incubator initiated a Helmholtz-wide discussion process and proposed long-term platforms to address selected highly relevant fields across the Association. As part of this process, five topic areas that are of particular strategic significance for the entire Association were subsequently identified. Platforms will be developed in these topic areas in the coming years.

- HIDA – platform for young researchers: Helmholtz is creating a new type of network for postgraduate training that builds upon six regional Helmholtz Information & Data Science Schools (HIDSS) with a total of over 250 new positions for doctoral candidates. In close cooperation with partner universities, the candidates receive funding of the highest level at the interface between domain research and information and data science. The Helmholtz Information & Data Science Academy (HIDA) functions as a Helmholtz-wide alliance. The collaborative nature of this alliance ensures that regional activities form value adding networks by establishing perfect-fit connections between the researchers.

- HAICU – platform for artificial intelligence and machine learning: Helmholtz is investing heavily in a pioneering network for artificial intelligence and machine learning. The Helmholtz Artificial Intelligence Cooperation Unit (HAICU) consists of one central and five local entities at various Helmholtz Centers. By enhancing AI in all six of its research fields, Helmholtz is placing a concerted focus on developing this cutting-edge technology to find solutions to the major challenges facing society.

- HIP – platform for image data technologies: Having a good command of imaging techniques and intelligent methods of analyzing image data is essential for all modern fields of research. The Helmholtz Imaging Platform aims to position Helmholtz as a leading provider, developer, and scientific user of groundbreaking technologies in the field of scientific imaging and image analysis.

- HMC – platform for metadata and knowledge systems: A metadata management system designed for the future is necessary in order to generate knowledge using data that exhibits a continually increasing degree of complexity and diversity, reproduce results, and be able to use these results more effectively. Promising approaches from all research fields will be made available on the Helmholtz Metadata Collaboration (HMC) platform.

- HIFIS – platform for basic technologies and services: Researchers receive a rapid network between the Helmholtz Centers, access to data and applications on the basis of cloud services, and support for developing software – in other words, the foundation for sophisticated, data-based research projects.

OPEN SCIENCE

The Helmholtz Open Science Coordination Office promotes and supports efforts to shape the transition to a culture of Open Science by serving as a partner for all of the stakeholders involved in this process at Helmholtz. It promotes dialog on this topic, provides momentum for Helmholtz, and represents the Association's positions on Open Science at the national and international level.

The office encourages expert exchange and the development of positions on the opportunities and challenges presented by Open Science within Helmholtz by establishing links between stakeholders from the areas of academia, information infrastructure, and administration. Providing this type of forum is crucial to integrating the stakeholders' skills and deploying them profitably on behalf of the entire spectrum of science at Helmholtz.

The Open Science Office acts as a driving force that picks up on relevant developments, categorizes them, and highlights potential options for action. Individual consultations, the work in and with the committees within Helmholtz, and the preparation and dissemination of relevant topics for a wide range of target groups – for example for the Helmholtz Juniors graduate students' initiative – serve as means of communication.

Finally, the Office serves to represent the Association's interests in external committees and organizations such as the German Initiative for Network Information (DINI), the European Association of Research and Technology Organisations (EARTO) at the European level, and the globally active Research Data Alliance (RDA).

SECTION III – STRATEGY PROCESS AT HELMHOLTZ

Digitalization is creating new challenges, which Helmholtz aims to address in the coming years based on the vision and goals outlined in Section I. Successfully implementing this vision and these goals requires a comprehensive process that includes designing, implementing, and continually reflecting on the Association's activities based on the six key questions described in the Helmholtz vision.

Helmholtz possesses incredible expertise in a wide range of areas. As set out in Section II, the Centers, research fields, Helmholtz Incubator, and Open Science Office are already devoting themselves to the challenges and opportunities presented by digitalization. In doing so, Helmholtz is tapping into the huge potential offered by interdisciplinary cooperation thanks to approaches that transcend the boundaries of its research fields.

Each Center and research field will actively contribute to the process, and supply and pass on its specialist expertise in order to jointly develop innovative solutions for the major challenges posed by digitalization.

The research field Information will position itself as a nucleus within the ongoing process. In the future, it will focus on the research and development of innovative basic algorithms, methods, tools, and concepts for creating, recording, storing, processing, analyzing, and reusing information in a secure and trustworthy way as part of an integrative approach in natural, technical, cognitive, and social systems. This research extends from the level of developing biological systems (particularly the human brain), to researching new materials and physical concepts, to integrating the knowledge acquired by the research field in the next generation of computers. In the context of the Helmholtz Digitalization Strategy, the research field Information is therefore an important pacesetter for all three of the roles described in the vision: Firstly, it will act as an initiator by (further) developing new and existing methodological and technological solutions, such as scalable algorithms for simulations and (big) data analytics, AI, research data management, and IT security. Secondly, it will serve as an enabler by developing and supplying information infrastructures in order to promote the implementation of innovative digitalized research processes in various scientific fields. Thirdly, it will function as a stakeholder by developing outstanding results to knowledge and solution-oriented interdisciplinary research. A few examples include the material sciences and quantum information, biophysics, structural biology and the neurosciences, simulation of the human brain, digital material design, and comprehensive modeling of the Earth system. In addition, the research field will contribute its expertise to technological impact assessments as well as responsible research and innovative practices with the aim of highlighting opportunities and risks on the journey from data to knowledge and action.

The research field Energy will focus intensively on the topic of digitalizing the energy transition (with the involvement of the research field Information). Human and infrastructural resources are currently being developed in the area of digitalization and data management. Key focal points of this work include using supercomputers and analyzing the requirements involved in efficiently evaluating ever-growing volumes of data using AI algorithms; utilizing digital platforms for energy materials research; data and model-driven approaches for understanding, predicting, and monitoring the behavior of plasma in nuclear fusion; and the further development of Open Access reference databases for security analyses.

A point of contact for digitalization and data management is appointed in each of the programs. This individual provides support for the digitalization strategy and the necessary cooperation between the research fields. In addition, the research field Energy will develop an overarching open access, open data, and open source strategy by the end of 2021.

The research field Earth and Environment addresses the challenges of the digital transformation by promoting the integration of data and workflows, improving interfaces between observation data and Earth system models, and providing simple, open access to data, repositories, and software. The research field develops valuable services for scientific users, politicians, industry, and citizens, integrates existing solutions, and enhances the digitalization of its research infrastructure for external users. Together with the universities, it educates the next generation of scientists, promotes talent, and trains the next generation of researchers in data science schools. The research field Earth and Environment uses comprehensive governance to address the transition to a culture of Open Access, Open Data, and Open Software, develops digital technology capacities and qualified staff. It conducts internationally competitive, collaborative research into Earth systems using digital technologies, data methods, quality assurance, and standards.

The digital transformation is also opening up a multitude of opportunities for linking and analyzing data in the research field Health. However, the handling of personal data presents special security requirements and is subject to legally defined framework conditions at the national and international levels and cannot be compared with those in other research fields. The health centers at Helmholtz are involved in shaping these challenges while balancing them with the special ethical responsibility they bear in terms of the common good. Their objective is to position themselves as role models so they can fully develop and utilize the opportunities presented by digitalization to conduct top-level international research.

The research field Aeronautics, Space, and Transport already took an important step toward digitalization back in 2017 when the German Aerospace Center adopted its Strategy 2030. Thanks to the ongoing strategic enhancement of its own research and development activities in coordination with its partners in government, science, and industry as well as new structures and approaches, the research field is strengthening Germany's position in the global competitive field and helping to actively shape the digital transformation. One of the steps carried out as part of Strategy 2030 was setting up a new cross-cutting area that pools together all activities and competencies relating to digitalization in the fields of aeronautics, space, and transport. This creates added technological value that goes beyond the research field's current focal points. It continues to follow this path consistently, and initiated developments will also be rigorously promoted in the future. In doing so, the research field addresses the enormous challenges faced by science, industry, and society and helps to utilize the potentials offered by the digital transformation.

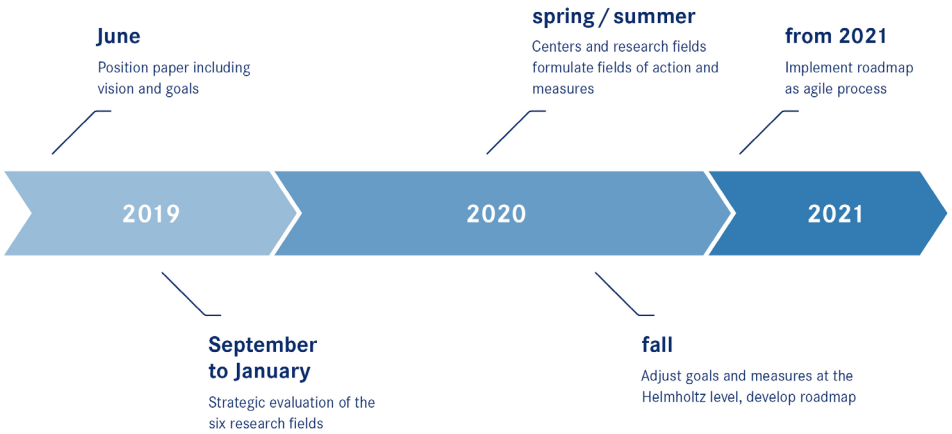
It is essential that digitalization continues to progress in the research field Matter so the scientific potential offered by modern, large-scale research facilities can be fully leveraged in the area of basic research and in the many fields of application. The exchange of knowledge and ideas as well as networking between researchers via modern collaborative methods and tools play a prominent role in the research field Matter. Thanks to the new topic of Data Management and Analysis in the Matter & Technologies program, the research field is pooling its resources so the opportunities of digitalization can be ideally exploited for the work conducted at its large-scale research facilities.

Helmholtz continues to develop its own strengths in the field of digitalization by consistently implementing the goals of the Information & Data Science Incubator. These efforts play a vital role in maintaining the leading international position held by its program-oriented research and enabling Helmholtz to offer links for cooperation with national and international partners in a highly attractive topic area. The initiated framework is being expanded in a targeted way and will be used to develop solutions throughout the Association. A governance structure will be established for management and evaluation purposes. Experts at the Incubator will contribute to the process of further developing and shaping the strategy. In particular, they will plan and support long-term, value adding activities and platforms that strengthen and flesh out the Helmholtz Digitalization Strategy.

The further course of the strategy process will be largely determined by the need to identify and exploit synergies between the six research fields and the Incubator. Ultimately, the goal is to ensure that Helmholtz leverages its potential to the full extent.

The position paper is to be available for the strategic evaluation of the research fields (from September 2019). In addition, a detailed analysis will examine the Helmholtz Centers' desired goals as well as ongoing or currently planned activities. The research fields will align themselves on this basis in 2020 and summarize their fields of action and measures at the Helmholtz level. A task force consisting of members from across Helmholtz will identify fields in which enhanced collaboration would be expedient and develop specific measures and tools for these fields. The strategy will begin to be implemented in 2021 with the integration of these measures and tools into projects so the tasks can be shared and carried out by the stakeholders, and with the development of a "self-organizing" monitoring process in the course of the fourth period of Program-oriented Funding (PoF IV).

By taking these steps, Helmholtz aims to position itself, set itself strategic goals on a roadmap and implement these at the operational level, ensuring that it has an agile process at its disposal in order to continue to develop in the future.



LEGAL INFORMATION

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