TRANSFORMATIVE PERSONAL HEALTH TECHNOLOGIES IN 2040

POLITECNICO
MILANO 1863

TECHNOLOGY FORESIGHT

Foreword

How will we prioritise health in 2040? This question encompasses multiple dimensions and stakeholders, necessitating a comprehensive strategy to address personal health, healthcare systems, and the health environment from a One-Health perspective.

At the Technology Foresight of Politecnico di Milano, we have conducted various individual and group activities to explore potential opportunities and challenges, preparing for a technological paradigm shift in personal health. Our primary goals are to identify the most disruptive technologies in the realm of personal health and assess their impact on shaping future scenarios. Our time frame extends from the present to 2040.

In our pursuit to answer the above question, key messages consistently emerged, encapsulating shared themes across diverse visions of future personal health and long-term priorities. While some concepts may be familiar, their true innovation lies in recognising that collective action and synergies are essential for genuine progress. This urgency is further emphasised by the need to shift from reactive to proactive healthcare, from generalised solutions to tailored, personalised ones, empowering the individual towards the pursuit of their well-being through awareness and engagement.

Donatella Sciuto
Rector, Politecnico di Milano

TAKE-HOME MESSAGES

1

Digital health: humans as data in hyper-connected societies

Data, data science, artificial intelligence, and communication: a steep acceleration affecting medicine from every point of view, merging it with technology. The promise is that of new opportunities for a longer and better life, but this requires new models, new professional figures, new educational paths and, above all, policies to manage such sensitive data and technologies that could potentially threaten human rights.

2

Proactive health care: from cure to prevention through prediction

In 2040, lifestyle awareness and improvement will be the new normal. By using wearables, implantable and similar devices, everyone will be constantly engaged in their own physical health, possibly able to predict and detect changes in their vital parameters at an early stage. Technologies will enable educated self-management and empowerment, yet at the risk of creating states of anxiety, obsessiveness and even hypochondria.

3

Mydicine: increasingly tailored medicine

Advancements in genetic technologies and the availability of a huge amount of health data will enable and drive personalised treatments, based on the individual's genetic heritage and their environment (physical as well as mental). Patients will be at the centre of the scene and will receive attention and treatments tailored for their unique needs.

4

Sustainability and equity: challenges to reduce the gaps

The pervasiveness of technology and its expected wide adoption must go hand in hand with sustainable development goals, in order not to exacerbate critical trends related to the scarcity of the planet's resources and health, on the one hand, and to avoid an uneven shift from community to individual healthcare that may not be accessible to the majority of the population, on the other hand.

TRANSFORMATIVE PERSONAL HEALTH TECHNOLOGIES IN 2040

STEEP Forces, Technologies and Insights

STEEP FORCES

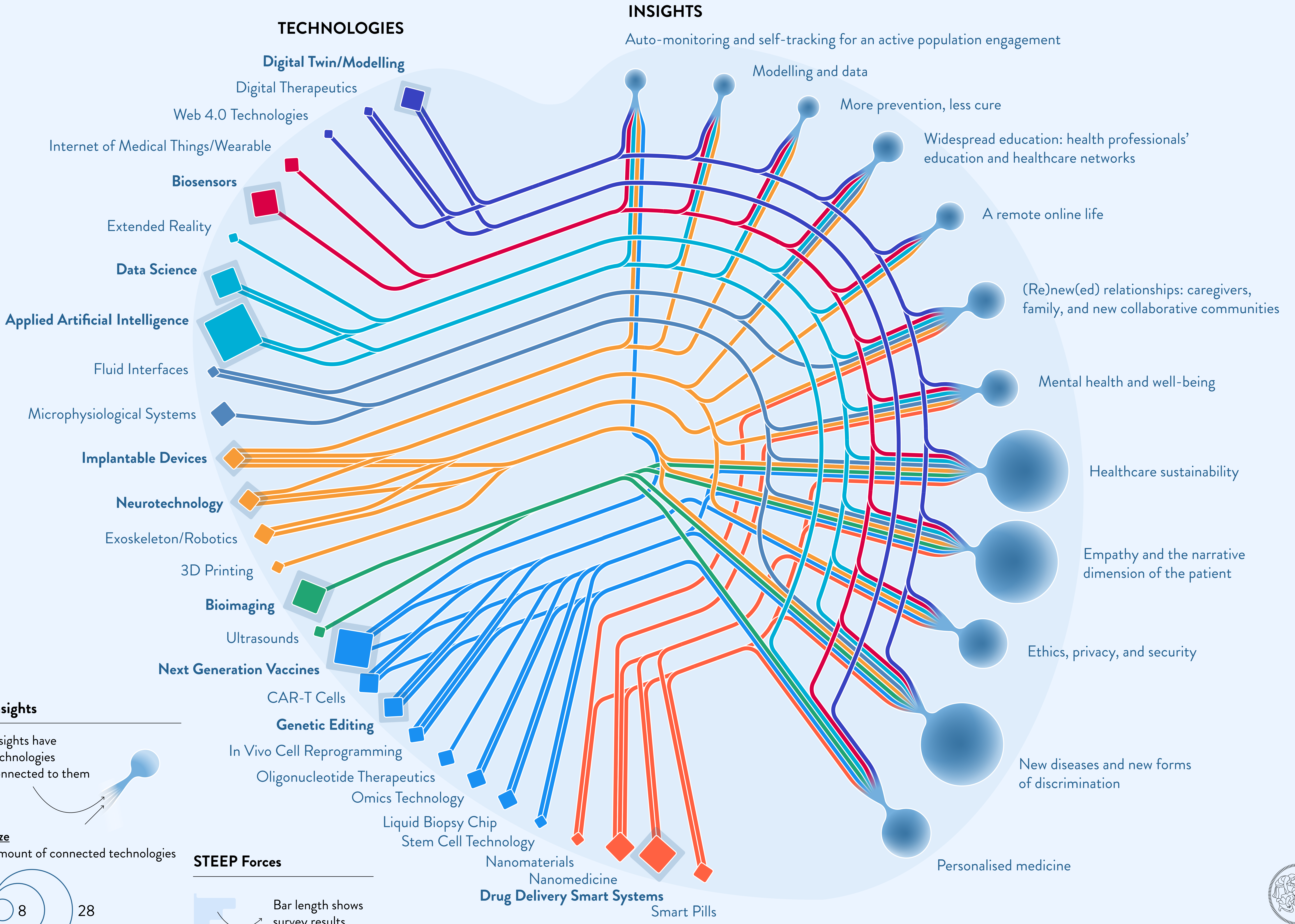
Social
- Ageing
- Non-communicable diseases
- Mental health
- Lifestyles
- Deepening disparities
- Demographic changes
- Beyond gender
- Migrations
- Work from everywhere
- Do it yourself

Technological
- Med(AI)cine
- Autonomous systems
- Hyper-connected
- Human enhancement
- Extended reality
- Robotics
- Digital twin
- Cryonics
- Genetic control
- Avatars

Environmental
- Pandemics
- Antimicrobial resistance
- Global climate changes
- Extreme events
- Environmental degradation
- Permafrost melting
- Pollution
- Food waste
- Circular economy
- Biodiversity loss

Economic
- Privatisation
- E-commerce
- Cost of living increase
- More prevention, less cure
- Insurance market players
- (Un)predictable instability
- New spaces, new relations
- Tech giants' pervasiveness
- Data exploitation
- Lack of skilled workers

Political
- Security
- Collapse of democracy
- Welfare
- (Trans)national identities
- Information and connection
- Geopolitical competition
- Nuclear paths
- Global commons
- The rise of ethical questions
- States like silos



HOW TO READ IT

Technologies

Size
Amount of votes
1 8 16

Highlight
Most relevant technologies emerged from the participants' survey results

Colour
Category
- Digital
- Wearable & Sensors
- Data, XR & AI
- Others
- Devices
- Imaging
- Genetics
- Nano

Insights

Insights have technologies connected to them

Size
Amount of connected technologies
8 28

STEEP Forces

Bar length shows survey results.

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TECHNOLOGY FORESIGHT

Introduction

The interplay between medicine and technology is getting stronger and stronger. Thus, several current paradigms are expected to remarkably change over the next years.

In order to explore how emerging technologies studied at Politecnico di Milano and worldwide have the potential to reshape personal health in 2040, an extensive eight-month foresight has been carried out by involving a group of 27 POLIMI researchers and external physicians. The selected technologies cover disease prediction, prevention, diagnosis, treatment, and rehabilitation.

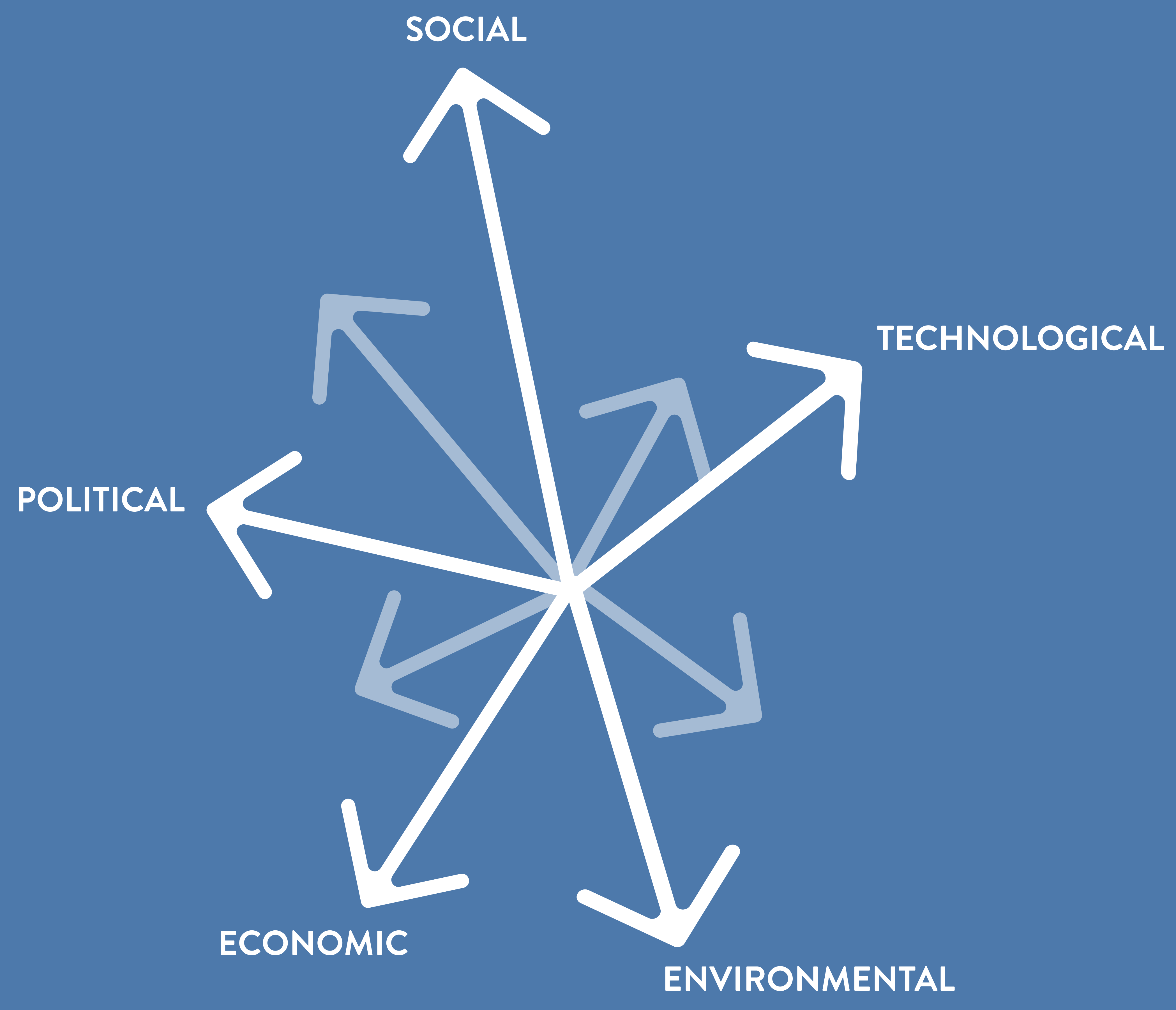
Alternative future scenarios and their implications have been investigated to identify opportunities, requirements, risks, and impacts. This multi-step process gathered insights from diverse sources, including desk research, interviews, group interactions, and surveys.

In the forthcoming sections, we have briefly summarised the most ground-breaking technologies and the key insights that shed light on ethical issues and raise thought-provoking questions.

What are STEEP Forces

STEEP (Social, Technological, Environmental, Economic, Political) forces are typically used to gather a coherent broad vision of the past, present, and future evolution of the overall context, to try to make sense of the multitude of available data, to keep an open perspective on what is going on.

STEEP Forces refer to trends that are "stable enough" to shape our future and general enough not to relate to the specific sphere of foresight. However, in this study, the ones that are expected to affect the future of health are highlighted and have been made available to generate the insights on the impact of relevant emerging technologies.



STEEP Forces

SOCIAL

AGEING · DEMOGRAPHIC CHANGES · **MENTAL HEALTH** · LIFESTYLES · DEEPENING DISPARITIES · NON-COMMUNICABLE DISEASES · BEYOND GENDER · MIGRATIONS · WORK FROM EVERYWHERE · DO IT YOURSELF

TECHNOLOGICAL

MED(AI)CINE · AUTONOMOUS SYSTEMS · HYPER-CONNECTED · HUMAN ENHANCEMENT · AVATARS · EXTENDED REALITY · ROBOTICS · DIGITAL TWIN · CRYONICS · GENETIC CONTROL

ENVIRONMENTAL

PANDEMICS · **ANTIMICROBIAL RESISTANCE** · **GLOBAL CLIMATE CHANGES** · EXTREME EVENTS · **ENVIRONMENTAL DEGRADATION** · PERMAFROST MELTING · POLLUTION · FOOD WASTE · CIRCULAR ECONOMY · BIODIVERSITY LOSS

ECONOMIC

PRIVATISATION · MORE PREVENTION, LESS CURE · **TECH GIANTS' PERVASIVENESS** · NEW SPACES, NEW RELATIONS · (UN)PREDICTABLE INSTABILITY · INSURANCE MARKET PLAYERS · **DATA EXPLOITATION** · E-COMMERCE · COST OF LIVING INCREASE · LACK OF SKILLED WORKERS

POLITICAL

SECURITY · COLLAPSE OF DEMOCRACY · **WELFARE** · (TRANS)NATIONAL IDENTITIES · INFORMATION & CONNECTION · **GEOPOLITICAL COMPETITION** · NUCLEAR PATHS · GLOBAL COMMONS · THE RISE OF ETHICAL QUESTIONS · STATES LIKE SILOS

The most relevant STEEP forces emerged from the participants' survey results are highlighted.

Selected long-term impact technologies

1 MAPPING THE LANDSCAPE: DESK RESEARCH ON THE FUTURE OF HEALTH

From foresight studies and scientific publications, we selected the 50 most recurrent technologies and innovations expected to be relevant and transformative.

2 EXPERTS' PRELIMINARY ANALYSIS

The first round of activities led to a preliminary identification of 28 core technologies.

3 EXTENDED AND IN-DEPTH ANALYSIS

To identify the most promising 10 technologies, we involved Politecnico di Milano's community and a group of physicians to express their opinion through a survey.

4 IMPACT AND RELEVANCE ASSESSMENT: THE FINAL OUTCOME*

- APPLIED ARTIFICIAL INTELLIGENCE
- NEXT GENERATIONS VACCINES
- BIOIMAGING
- DRUG DELIVERY SMART SYSTEMS
- DATA SCIENCE
- BIOSENSORS
- DIGITAL TWIN/MODELLING
- GENETIC EDITING
- IMPLANTABLE DEVICES
- NEUROTECHNOLOGY

*Bar length shows the survey's results.

Technologies

APPLIED ARTIFICIAL INTELLIGENCE
EXTENDED REALITY
DATA SCIENCE

DATA, XR & AI

CAR-T CELLS
GENETIC EDITING
IN VIVO CELL REPROGRAMMING
LIQUID BIOPSY CHIP
NEXT GENERATIONS VACCINES
OLIGONUCLEOTIDE THERAPEUTICS
OMICS TECHNOLOGY
STEM CELL TECHNOLOGY

GENETICS

DIGITAL THERAPEUTICS
DIGITAL TWIN/MODELLING
WEB 4.0 TECHNOLOGIES

DIGITAL

DRUG DELIVERY SMART SYSTEMS
NANOMATERIALS
NANOMEDICINE
SMART PILLS

NANO

BIOIMAGING
ULTRASOUNDS

IMAGING

BIOSENSORS
INTERNET OF MEDICAL THINGS/WEARABLE

WEARABLE & SENSOR

3D PRINTING
EXOSKELETON/ROBOTICS
IMPLANTABLE DEVICES
NEUROTECHNOLOGY

DEVICES

FLUID INTERFACES
MICROPHYSIOLOGICAL SYSTEMS

OTHERS

The most relevant technologies emerged from the participants' survey results are highlighted.

APPLIED AI

Applied Artificial Intelligence (Applied AI) involves the pragmatic deployment of advanced Artificial Intelligence methodologies to address tangible challenges across manifold domains. It encompasses the use of cutting-edge techniques, including among others machine learning algorithms, natural language processing, computer vision, and robotics, to devise hardware and software systems proficient in executing tasks conventionally requiring human-like cognitive abilities.
In the context of medicine, Applied AI offers the opportunity to analyse large datasets (e.g., medical images, genomic data, and other health records) to extract knowledge, personalise and discover treatments, automate and speed processes, and, in general, assist and support healthcare professionals.

EXAMPLES OF POTENTIAL FIELDS OF APPLICATION

Health monitoring data interpretation | AI-enabled prosthetics | Better sense of patient data | Enhanced visualization during surgery | Improved data collection from medical settings | AI-enabled artificial organs

PHASES

PREDICTION | PREVENTION | DIAGNOSIS | TREATMENT | REHABILITATION

OPPORTUNITIES

→ Support and automation towards effectiveness and efficiency
→ Physician's focus on the narrative and holistic dimension of the patient
→ Prompt analysis and detection of large quantities of collected data improving prevention and treatment

REQUIREMENTS

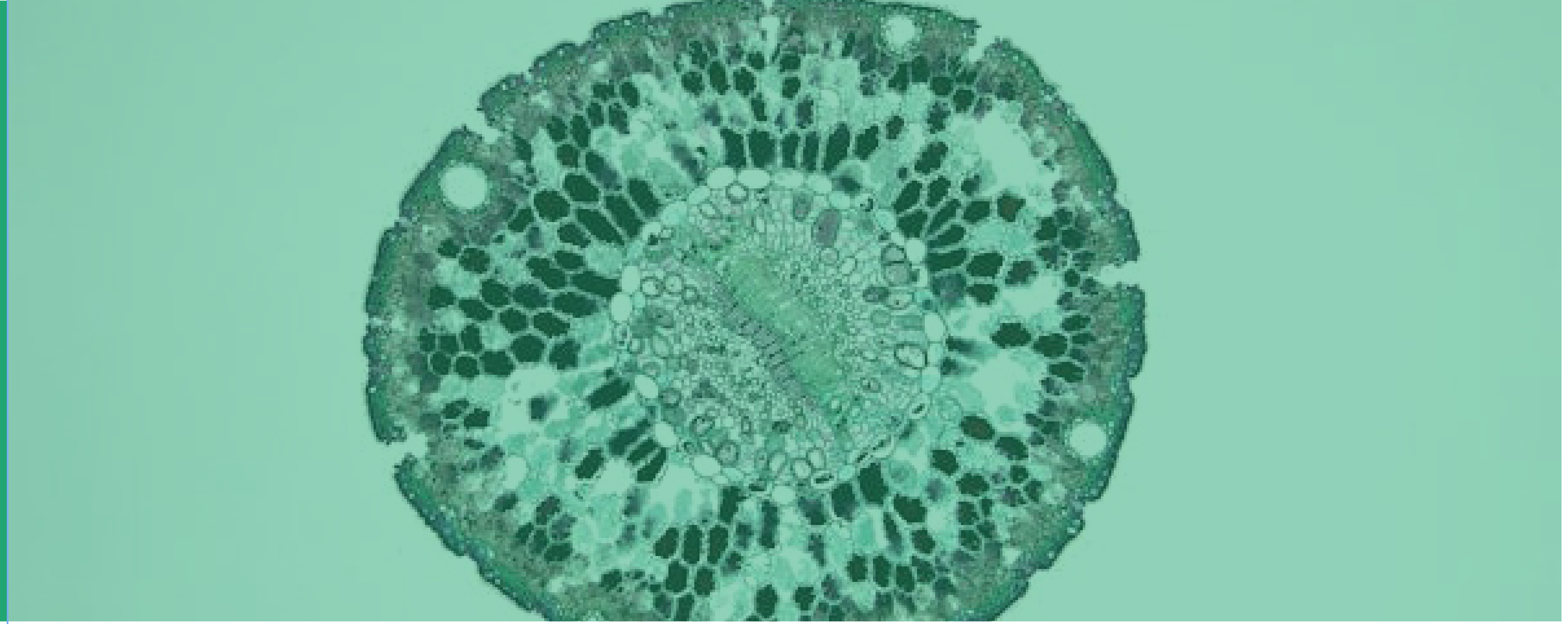
→ Environmental/economic sustainability
→ New risk models associated to collected/processed data
→ Reliability, trustability and explainability
→ Human in the loop approach

RISKS

→ Poor outcomes (bias, low-quality data, lack of transparency, use in inappropriate contexts)
→ Leaks of personal data and unclear accountability
→ Bias leading to safety-critical errors

IMPACTS

→ Availability of high-profile competences at a larger scale, shareable among different communities



BIOIMAGING

Biomedical imaging techniques serve diagnostic and, occasionally, therapeutic functions, including the acquisition and analysis of data across the electromagnetic spectrum. These modalities play a pivotal role in elucidating the structural and functional intricacies of biological systems, thus facilitating comprehensive understanding and targeted intervention in pathophysiological processes. Its non-invasiveness is crucial in various fields of research, diagnostics, and medical treatments, enabling longitudinal studies over time.

EXAMPLES OF POTENTIAL FIELDS OF APPLICATION

Diagnostic | Intelligent disease mapping | Computer-aided diagnosis | Hyperspectral imaging system | Bio-electromagnetic technologies | Bioanalytical sensors | Image-guide surgery | Magnetic Resonance Imaging | Tracers and contrast devices | Biomedical visualisation and data augmentation

PHASES

PREDICTION | **PREVENTION** | **DIAGNOSIS** | **TREATMENT** | REHABILITATION

OPPORTUNITIES

→ Monitoring of metabolites that can be used as biomarkers for disease identification, progress and response to treatment
→ Improved diagnosis and therapy
→ Expansion of imaging applications to new areas (e.g., gene expression, functional brain organisation)

REQUIREMENTS

→ Environmental/economic sustainability

RISKS

→ Risk of stratification and treatment strategies
→ Biomarkers validation

IMPACTS

→ More effective and timely diagnosis, and treatment improvement
→ Risks vs benefits and costs vs effectiveness trade-off balance

BIOSENSORS

A biosensor is a device measuring biological or chemical reactions through the generation of signals proportionate to the concentration of an analyte participating in the reaction. Biosensors have a very wide range of applications, including but not limited to disease monitoring, pharmaceutical research, pathogenic microorganisms, disease-related biomarkers, and detection of environmental pollutants. Noteworthy subcategories of biosensors encompass wearables, portable devices, and ingestible sensor systems, each tailored to address distinct operational contexts and analytical requirements within the scope of biomedical and environmental sciences.

EXAMPLES OF POTENTIAL FIELDS OF APPLICATION

Blood parameters | Cardiac data | Metabolic markers | Sleep quality | Stress and cognitive decline

PHASES

PREDICTION | **PREVENTION** | **DIAGNOSIS** | TREATMENT | REHABILITATION

OPPORTUNITIES

→ Accurate, precise, and early diagnosis of emerging diseases
→ Collection of clinical parameters without the need for sampling and laboratory tests
→ Real-time longitudinal data collection

REQUIREMENTS

→ Extreme precision
→ Biodegradability

RISKS

→ The complexity of the technologies required
→ Risks related to the individual use of sensors (anxiety, stress and/or hypochondria)

IMPACTS

→ Optimise and speed up both clinical development and longitudinal monitoring of drug efficacy and safety

DATA SCIENCE

In the realm of healthcare, substantial datasets replete with pertinent information on patient demographics, treatment modalities, diagnostic outcomes, insurance particulars, and other relevant variables are routinely generated. Within this context, data science assumes a critical role, serving as a foundational framework for facilitating the systematic processing, management, analysis, interpretation, and integration of these datasets. Through the application of rigorous scientific methodologies, advanced data mining techniques, machine learning algorithms, and big data analytics, enable healthcare practitioners to extract actionable insights essential for informed decision-making and optimised patient care delivery.

EXAMPLES OF POTENTIAL FIELDS OF APPLICATION

Data cleaning · Data mining · Data preparation · Data analysis · Practical insights · Decision-making

PHASES

PREDICTION · PREVENTION · DIAGNOSIS · TREATMENT · REHABILITATION

OPPORTUNITIES

Data-driven insights can:
→ Improve patient outcomes
→ Enhance clinical decision-making
→ Advance our understanding of human health and disease
→ Personalised medicine

REQUIREMENTS

→ Data availability
→ Creation of predictive models
→ Integrated data management
→ Management structures and criteria for discerning useful data

RISKS

→ Lack of data, data quality / accuracy
→ Bias and errors in data interpretation
→ Use of invalidated and uninterpreted data
→ Continuous monitoring
→ Excessive self-diagnosis and development of anxiety and hypochondria
→ Privacy/cybersecurity
→ Lack of skills on the medical side to interpret huge amounts of data

IMPACTS

→ Models' development
→ Improvement of the management, prevention, and prediction based on data
→ Healthcare expenditure related to treatment reduction

DIGITAL TWIN/MODELLING

A Digital Twin is a set of virtual information constructs that mimics the structure, context, and behaviour of a natural, engineered, or social system. It is dynamically updated with data from its physical twin, has a predictive capability, and informs decisions that realise value. Health digital twins (HDTs) are virtual representations of patients, derived from diverse patient data sources, population data, and real-time updates concerning patient and environmental variables. Through meticulous application, HDTs can simulate random deviations in the digital twin to elucidate anticipated behaviours of the physical counterpart, thereby offering revolutionary implications in precision medicine, clinical trial methodologies, and public health initiatives.

EXAMPLES OF POTENTIAL FIELDS OF APPLICATION

- Access to data-driven insights regarding operational strategies, capacity, staffing and care models
- Monitoring
- Development of a unique model for each patient

PHASES

PREDICTION | **PREVENTION** | **DIAGNOSIS** | **TREATMENT** | REHABILITATION

OPPORTUNITIES

→ Prediction of disease progression
→ Identification of high-risk individuals
→ Recommendation of preventive measures
→ Monitoring without the implications of presence checks
→ Relief for the healthcare system
→ Personalised medicine

REQUIREMENTS

→ Creation of predictive models
→ Data collection and data availability
→ Interoperability of data
→ Development of decision models (with probabilistic formulation)

RISKS

→ Lack of systems allowing for interoperability of data
→ Privacy of data and non-medical uses
→ Overconfidence in the adoption of the tool within the clinical decision-making process

IMPACTS

→ Reshaping industries to increase efficiency and identify issues
→ Treatment of patients as virtualised standalone assets
→ Improvement in treatment and diagnostics within hospitals and for individual patients

DRUG DELIVERY SMART SYSTEMS

Drug delivery pertains to the methodologies, formulations, technologies, and mechanisms employed to transport therapeutic agents within the body with precision, ensuring their safe and effective delivery to achieve therapeutic objectives. Drug delivery smart systems have demonstrated the capacity to reduce dosing frequency while maintaining therapeutic drug concentrations within targeted anatomical sites over prolonged periods. In this context, these controlled-release systems offer valuable insights and remarkable attributes for attenuating fluctuations in drug concentrations, mitigating drug-related toxicities, and enhancing therapeutic efficacy.

EXAMPLES OF POTENTIAL FIELDS OF APPLICATION

Medications (e.g., cancer therapy, imaging)

PHASES

PREDICTION | PREVENTION | DIAGNOSIS | **TREATMENT** | **REHABILITATION**

OPPORTUNITIES

→ Precise targeting of diseased cells or tissues, minimising harmful effects on healthy cells
→ Release at optimal intervals and dosages to maintain therapeutic levels in the body
→ Off-target effects minimisation
→ New drug development
→ Pharmacokinetics and pharmacodynamics of therapeutic agents improvement
→ New modes of administration (transdermal, ocular, nasal)

REQUIREMENTS

→ Good stability of the encapsulated drug
→ Biocompatibilty of materials
→ Targeted release and delivery

RISKS

→ Lack of necessary precision
→ Risk related with the long-term release of microscopic objects is not yet known

IMPACTS

→ Personalised treatments based on patient data, genetic profiles, and real-time monitoring, through the combination of drug delivery systems with artificial intelligence
→ Personalised medicine

GENETIC EDITING

Genetic editing is a methodology used to enact precise modifications to the DNA of cells or organisms, facilitating targeted additions, deletions, or alterations within the genome. This technique is applicable to somatic cells, where resultant modifications are non-heritable, as well as to germline cells, where edits may be intended for non-reproductive or reproductive purposes.

CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) represents a technology leveraged by research scientists to selectively manipulate the genetic material of living organisms. Derived from naturally occurring genome editing mechanisms observed in bacteria, CRISPR has been adapted for use in laboratory settings, offering a powerful means for targeted genetic editing.

EXAMPLES OF POTENTIAL FIELDS OF APPLICATION

Single gene testing · DNA sequencing · DNA shearing · Exome sequencing · Genome sequencing · DNA bar coding · Large-scale genetic or genomic testing

PHASES

PREDICTION · **PREVENTION** · **DIAGNOSIS** · **TREATMENT** · REHABILITATION

OPPORTUNITIES

→ Genetic tests could provide a basis for patient information, without deterministically directing the evolution of a person's health
→ Personalised medicine
→ Creation of criteria for classifying people's phenotypes by cross-referencing family heritage, medical records and daily data
→ Profiling and prevention of potential risks

REQUIREMENTS

→ Definition of criteria for ethical and legal applications

RISKS

→ Genetic tests do not always make it possible to determine with absolute certainty whether, when and at what level of severity the person will become ill
→ Healthy people may become "pre-patients" for a long time before developing the disease
→ Possible bias in classification

IMPACTS

→ Implementation of a series of prevention and early diagnosis measures to prevent or delay the onset of the disease

IMPLANTABLE DEVICES

An implantable device is an active medical device intended to be fully or partially inserted into the human body for diagnostic or therapeutic purposes, with the intention of remaining in place. Due to their direct and long-term contact with the body, implantable devices are subject to rigorous standards and requirements to ensure the health and safety of patients.

Not only implantable, but also wearable technologies will play a central role. The ubiquity of wearable computing elements is on the rise, albeit hindered by inherent limitations in resolution and bandwidth imposed by current digital technology paradigms. This evolution now intersects with biological frameworks and processes, paving the way for a transformative era in healthcare.

EXAMPLES OF POTENTIAL FIELDS OF APPLICATION

Remote patient monitoring | Glucose monitoring | Heart rate monitoring | Connected contact lenses | Parkinson's disease monitoring | Depression and mood monitoring | Ingestible sensors connected inhalers

PHASES

PREDICTION | PREVENTION | DIAGNOSIS | TREATMENT | REHABILITATION

OPPORTUNITIES

→ Continuous monitoring of vital parameters
→ Citizen-centred care and 6P medicine (Preventive, Predictive, Participatory, Personalized, Psychosocial, Platforms)
→ Development of new families of wearable sensors (smart rings, smart glasses)

REQUIREMENTS

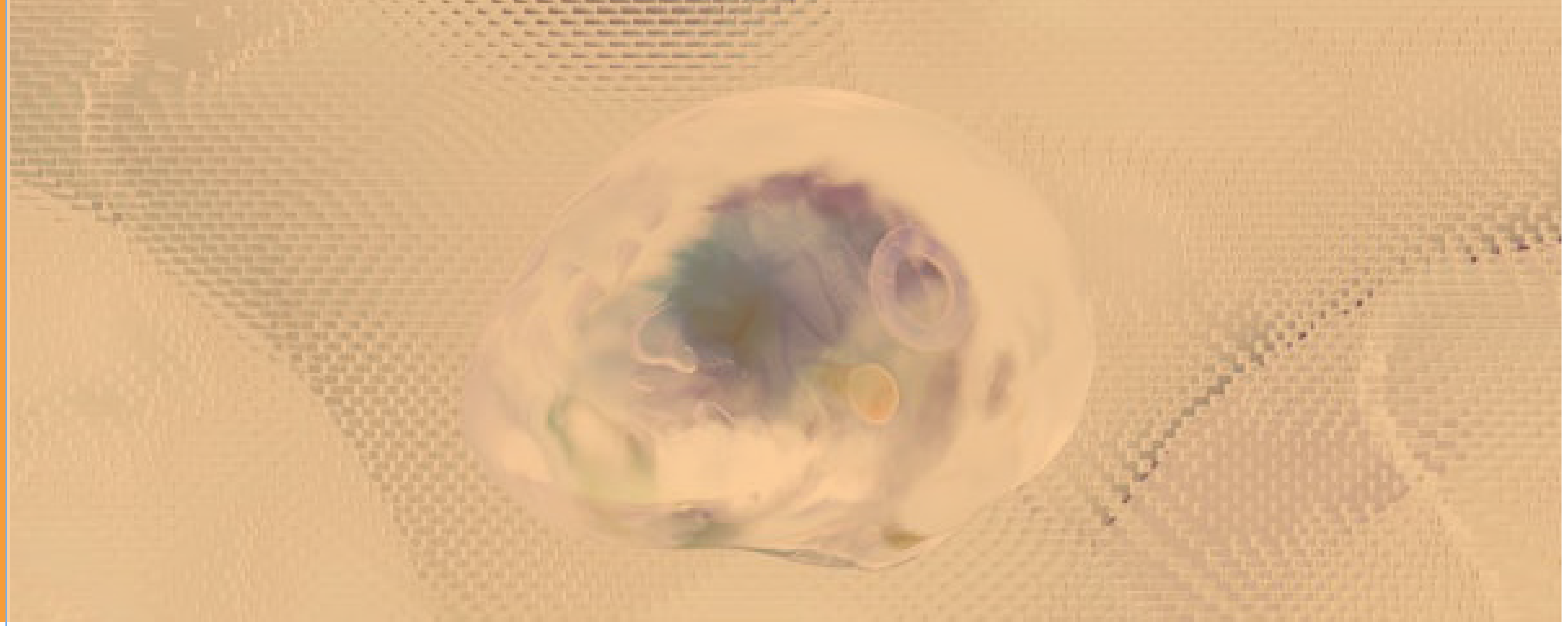
→ Massification of wearable and implantable technologies
→ Availability and affordability
→ Miniaturized batteries
→ Data analysis
→ Data management models
→ Organisation of information campaigns

RISKS

→ Psychological stress, agitation and/or hypochondria due to control and technological dependence on continuous measurement
→ Over-diagnosis and obsession
→ Invasiveness of drug delivery for implantable devices
→ Possibility of self-determination and the choice to refuse continuous control
→ Medicalisation of existence
→ Lack of common platforms for data collection and analysis

IMPACTS

→ Quasi-normal lifestyle for individuals requiring medications and continuous monitoring



NEUROTECHNOLOGY

Neurotechnology aims to comprehend, enhance, and restore functionality to the nervous system. A neurotech device is a technological device designed to continuously modulate and stimulate neural impulses. While a segment of neurotechnology is dedicated to investigative endeavours, examining mental health disorders or sleep patterns, its use is progressively expanding to modulate brain function or nervous system activity for therapeutic or rehabilitative objectives.

Neurological conditions such as Parkinson's disease, Alzheimer's disease, major depression, and brain injuries stand to benefit significantly from neurotechnological interventions. The diffusion of such devices holds immense promise in healthcare, particularly as demographic shifts lead to an ageing population and increased life expectancy, consequently heightening the demand for efficacious treatments for neurological ailments.

EXAMPLES OF POTENTIAL FIELDS OF APPLICATION

Brain imaging | Neurostimulation | Neuro-devices

PHASES

PREDICTION | PREVENTION | DIAGNOSIS | TREATMENT | REHABILITATION

OPPORTUNITIES

→ Influence on the brain or nervous system for therapeutic or rehabilitation purposes
→ Conditions such as Parkinson's, Alzheimer's, major depression and brain injuries could find relief thanks to neurotechnology
→ Monitoring and treating mental health conditions
→ Better pain management
→ Cognitive improvement
→ Less side effects due to the use/abuse of psychotropic drugs

REQUIREMENTS

→ Creation of neural network schemes
→ Access to the operation of the individual

RISKS

→ Ethical admissibility of heteronomous intervention in the cognitive process
→ Unauthorised access to sensitive information stored in the brain

IMPACTS

→ The demand for effective treatments for neurological disorders will increase as the population ages and life expectancy increases and neurotechnology can help to control neurological disorders

NEXT GENERATION VACCINES

The foundation of next-generation vaccines lies in the identification of specific proteins derived from the infectious agent, which evokes an immune response akin to that elicited by the intact pathogen. Cancer vaccines represent a subset of immunotherapeutic interventions aimed at instructing the immune system to recognise and eradicate malignant cells by presenting antigens characteristic of cancer cells.

Currently, vaccines stand as the foremost efficacious means for averting widespread transmission of infectious diseases. Global endeavours are concentrated on fighting and ultimately eradicating COVID-19, with dedicated efforts toward vaccine development initiated upon its declaration as a pandemic.

EXAMPLES OF POTENTIAL FIELDS OF APPLICATION

Human Papilloma Virus vaccines · Antigen vaccines · DNA vaccines · Hepatitis B vaccines · Cancer vaccines · Dendritic cell vaccines · Anti-idiotype vaccines

PHASES

PREDICTION · PREVENTION · DIAGNOSIS · TREATMENT · REHABILITATION

OPPORTUNITIES

→ They are able to self-replicate with a very low dosage and prolonged efficacy
→ It teaches the organism to produce more mRNA
→ Opportunity to vaccinate new target groups

REQUIREMENTS

→ Pre-clinical testing that includes in vitro studies and studies in animal models through which the mechanism of action is defined
→ Education of the population on correct health choices (also about vaccines)
→ Establish a legislative framework of new compulsory vaccinations

RISKS

→ Refusal to undergo vaccinations

IMPACTS

→ Through the massification of people subjected to prevention it enables primary prevention strategies to be undertaken to avoid the spread of contagious diseases
→ Massification of people subjected to prevention

INSIGHTS

The following descriptions are the result of the insight phase, built on conversations generated by the analysis of alternative futures, in which possible paths towards the futures of personal health were generated.

They derive from the analysis of alternative visions of the future associated with health, with both positive and negative elements, aiming at understanding the opportunities and challenges posed by each context and at identifying the conditions that will allow us to move in the preferred direction also in relation to the different stakeholders (administrations, medical professions, patients, caregivers, ...), without neglecting risks and possible barriers.

AUTO-MONITORING AND SELF-TRACKING FOR AN ACTIVE POPULATION ENGAGEMENT

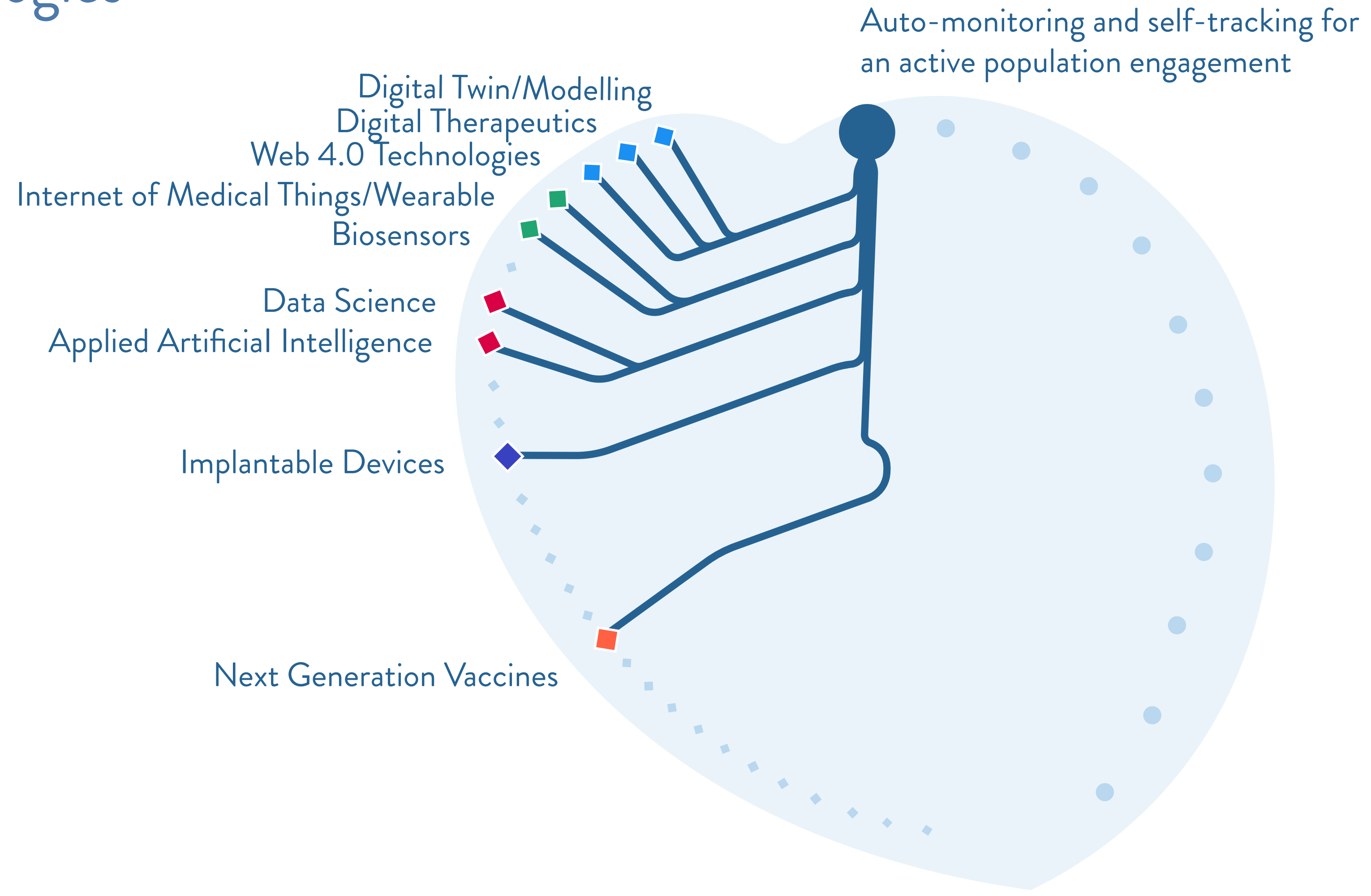
The **active involvement of patients**, families, and the community at large is essential to advance predictive models. The overall goal is to promote autonomy and self-sufficiency by empowering people to effectively manage their own care.

To this end, harnessing **collective intelligence** through information crowdsourcing is crucial. It is necessary to promote awareness through widespread dissemination and create care networks that incorporate voluntary resources as additional support to the healthcare system.

Self-monitoring could support the maintenance of physical and mental health through constant monitoring of vital parameters. Collectively, continuous monitoring could benefit healthcare by providing data for predictive and preventive modelling.

At the same time, the implications of **self-monitoring** are manifold. Sociality could change and psychological risks increase in a context where existence is pervaded by progressive medicalisation.

Technologies



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MODELLING AND DATA

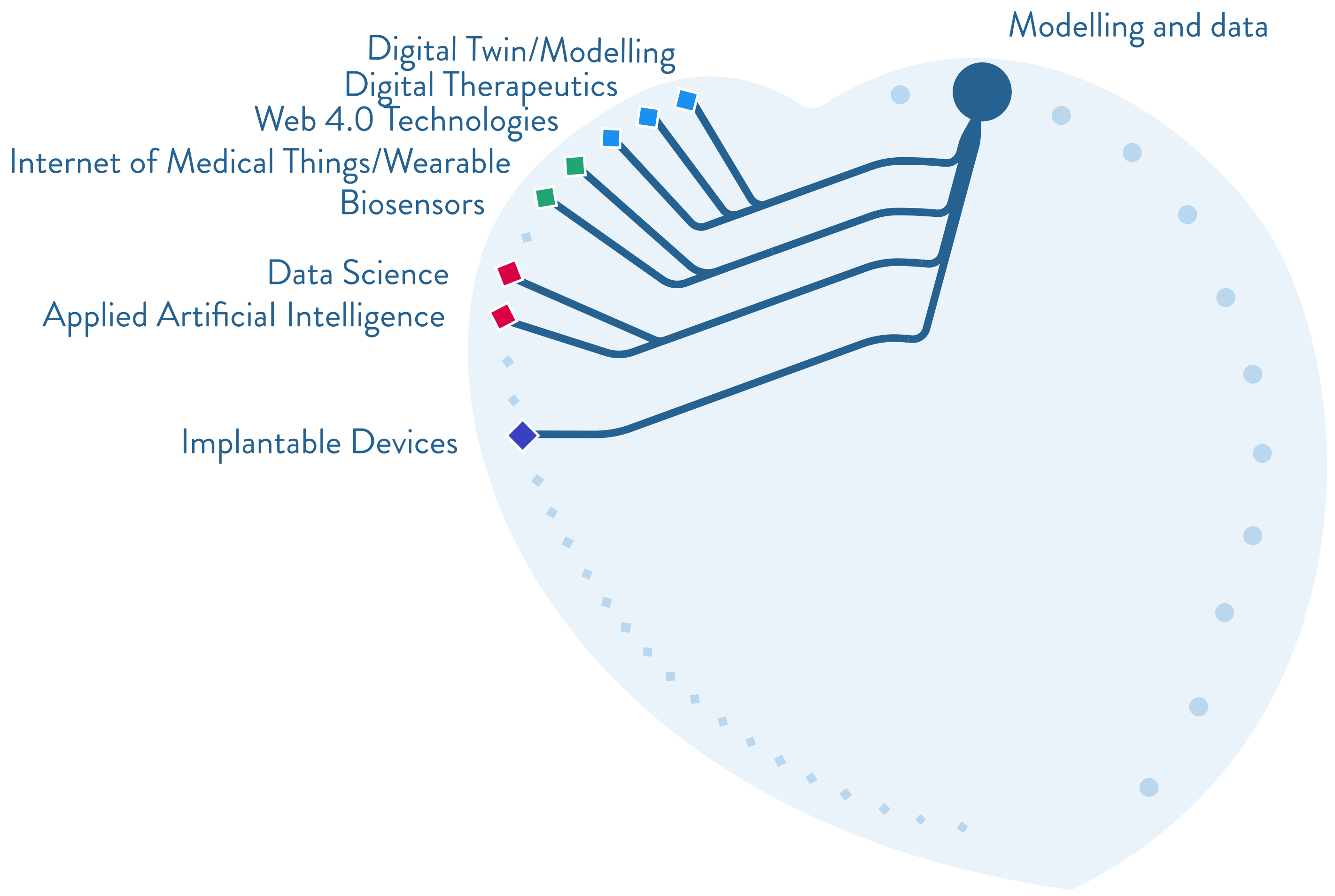
The availability of data and the ability to analyse them are the new gold rush to predict and prevent diseases. It is necessary to develop simulation systems and technologies to implement clinical research based on **real world data** and define new criteria for **predictive modelling**.

Advanced predictive models and extensive data availability can enhance health outcomes. However, due to the intimate nature of this data, **data protection** and **new privacy paradigms** are essential to prevent unauthorised use.

An information system for citizens must be developed so that they are aware of the use of monitoring systems.

Situations where individual narratives are depersonalised through the use of models and data, as well as their inappropriate use for non-medical purposes, raise significant questions for the future.

Technologies



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MORE PREVENTION, LESS CURE

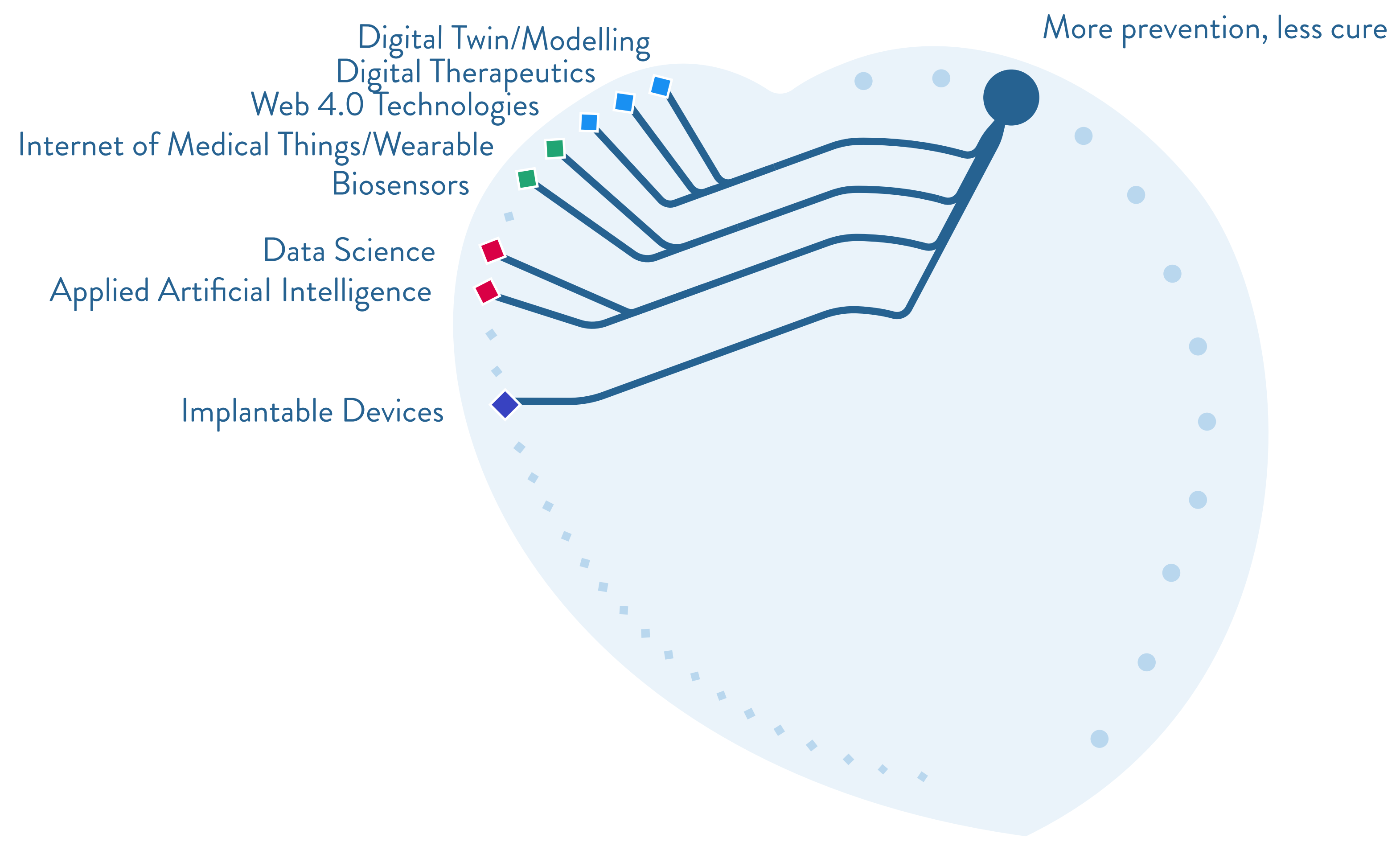
Prevention will be a central pillar in the health of the future: data availability and the development of new models to make the most out of it, also enabling disease prediction, will increase and provide the foundations for implementing personalised prevention plans.

Healthier and more conscious **lifestyles** will be promoted, spanning over various areas (such as nutrition and physical activity).

Governments will develop new prevention campaigns, at the risk of coercively influencing individual behaviour and lifestyle choices, eventually adopting sensibilisation approaches towards those who do not adhere, thus ascribing diseases to **individual responsibility**.

Indeed, **costs** can be a critical aspect, and the ability to balance the investments necessary to promote prevention with the subsequent decrease of treatment costs will be pivotal. The possible shift of costs from the collectivity towards the empowered individual will also need consideration.

Technologies



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WIDESPREAD EDUCATION: HEALTH PROFESSIONALS' EDUCATION AND HEALTHCARE NETWORKS

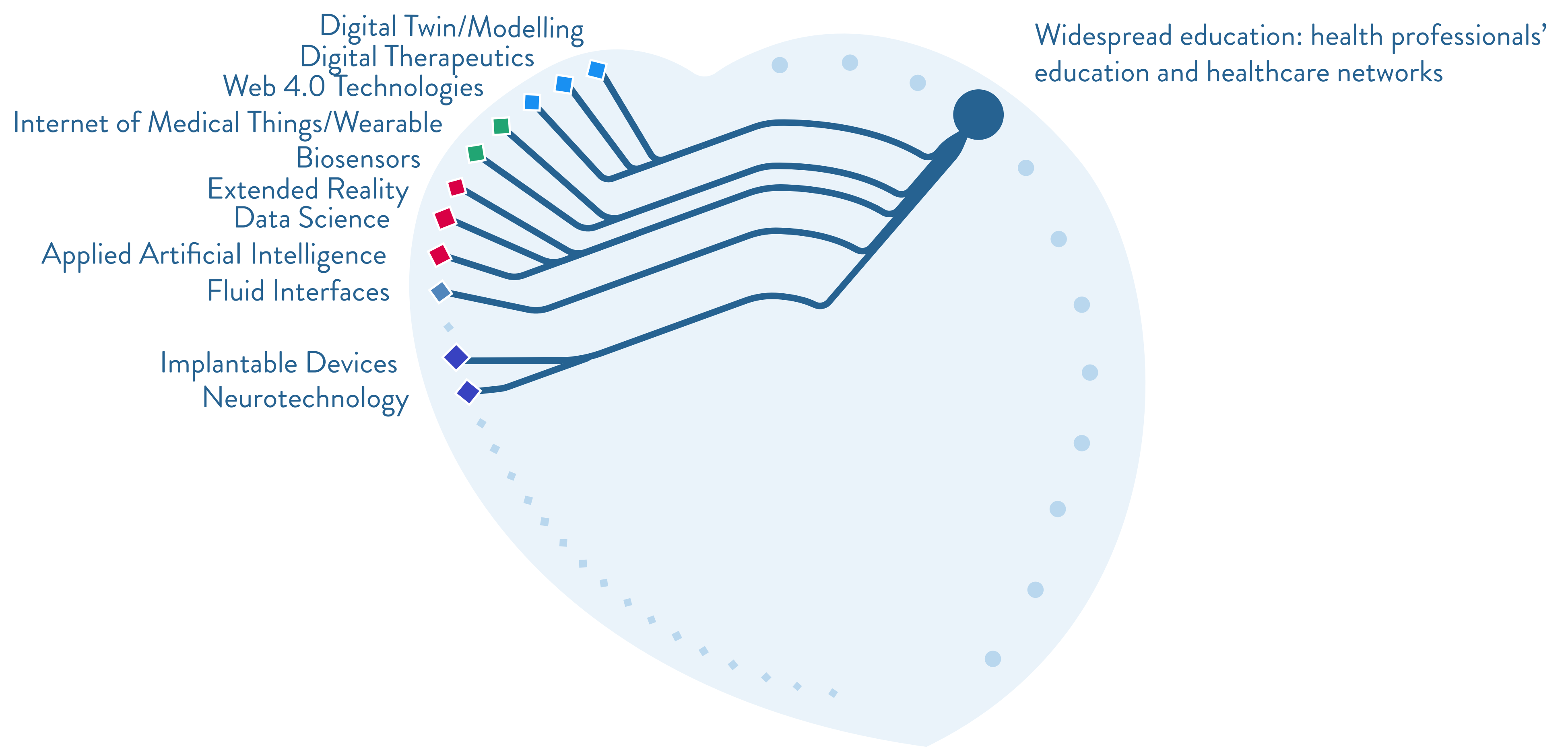
Education becomes both an opportunity and a challenge: it is necessary to train new generations in **new professionals** capable of analysing data, developing models and criteria for managing data, increasing knowledge, and matching academic research with socially emerging needs.

The interoperability of healthcare facilities and hospitals is based on the possibility of communicating with each other through infrastructures to support data collection, integration, storage, and management. **Patient data sharing and knowledge exchange** are essential pillars in the perspective of progressive virtualisation and real-time/longitudinal availability of data.

Shared access and validated data could **create networks of practitioners and researchers** who team up to provide an effective action against diseases and towards patients.

For these reasons, education must be extended to the **entire population**, and it is also necessary to create **digital literacy paths** for generations that were not born with it. Education also include other key aspects, e.g. **information** on nutrition and elements for conscious and healthy lifestyles, the importance of physical activity, and the relationship between physical and mental well-being.

Technologies



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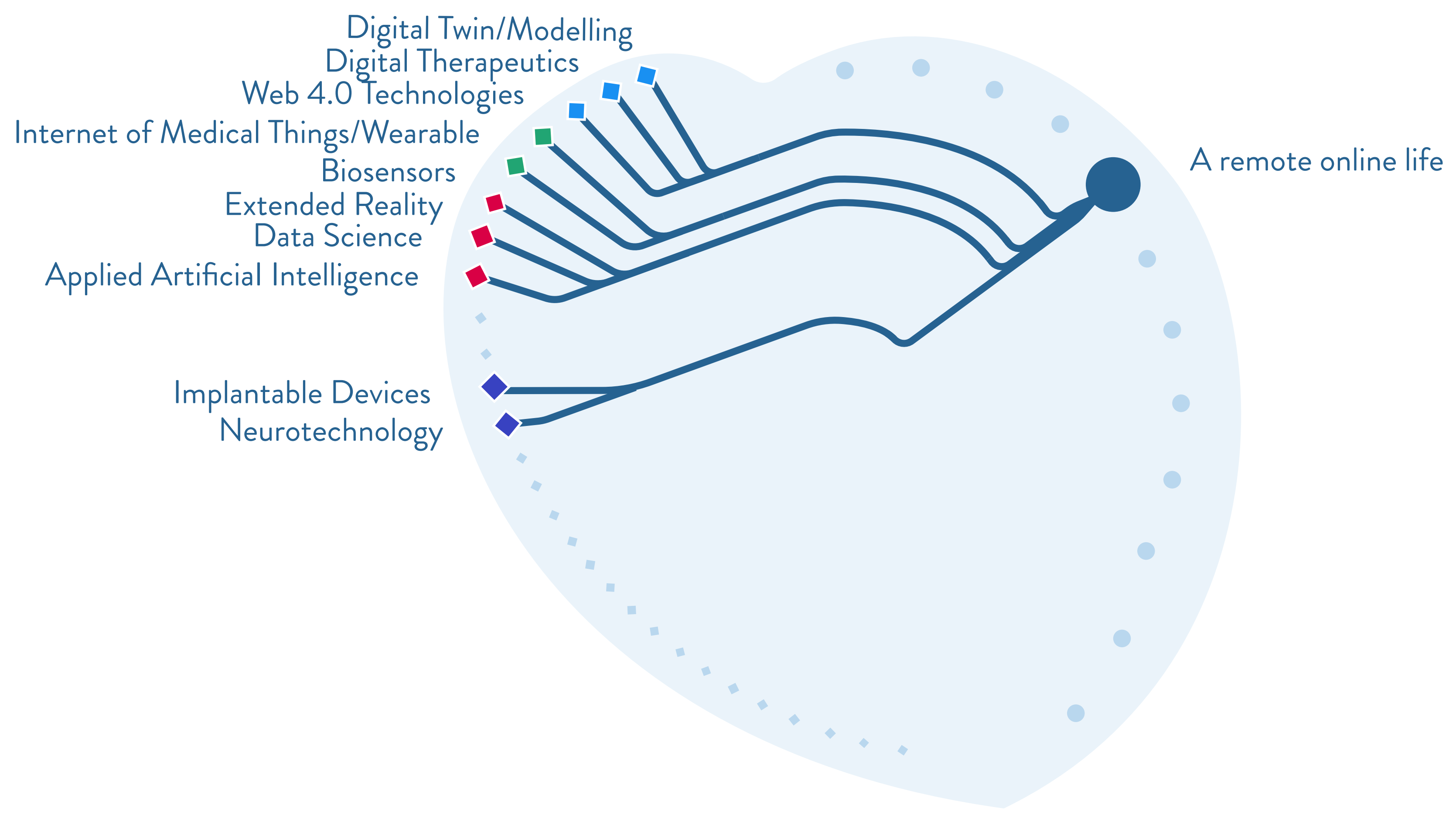
A REMOTE ONLINE LIFE

In the forthcoming years, the surge in remote living will permeate all aspects of relationships. For instance, **smart working** will emerge as an opportunity for managing family responsibilities, spanning from childcare to eldercare. Additionally, there will be instances where **human interaction** will blend seamlessly with **digital interfaces** to cultivate more continuous connections, particularly with vulnerable populations. Therefore, anticipating a **decentralised organization** of healthcare services, extending even into remote areas, will become imperative.

Moreover, **domestic environments** will need to be opportunely organised and extended to include the necessary technologies in an inclusive way.

The **virtual and online trend** will also enhance opportunities for remote assistance and participation in surgeries and other medical practices, facilitating the effective sharing of expertise and excellence.

Technologies



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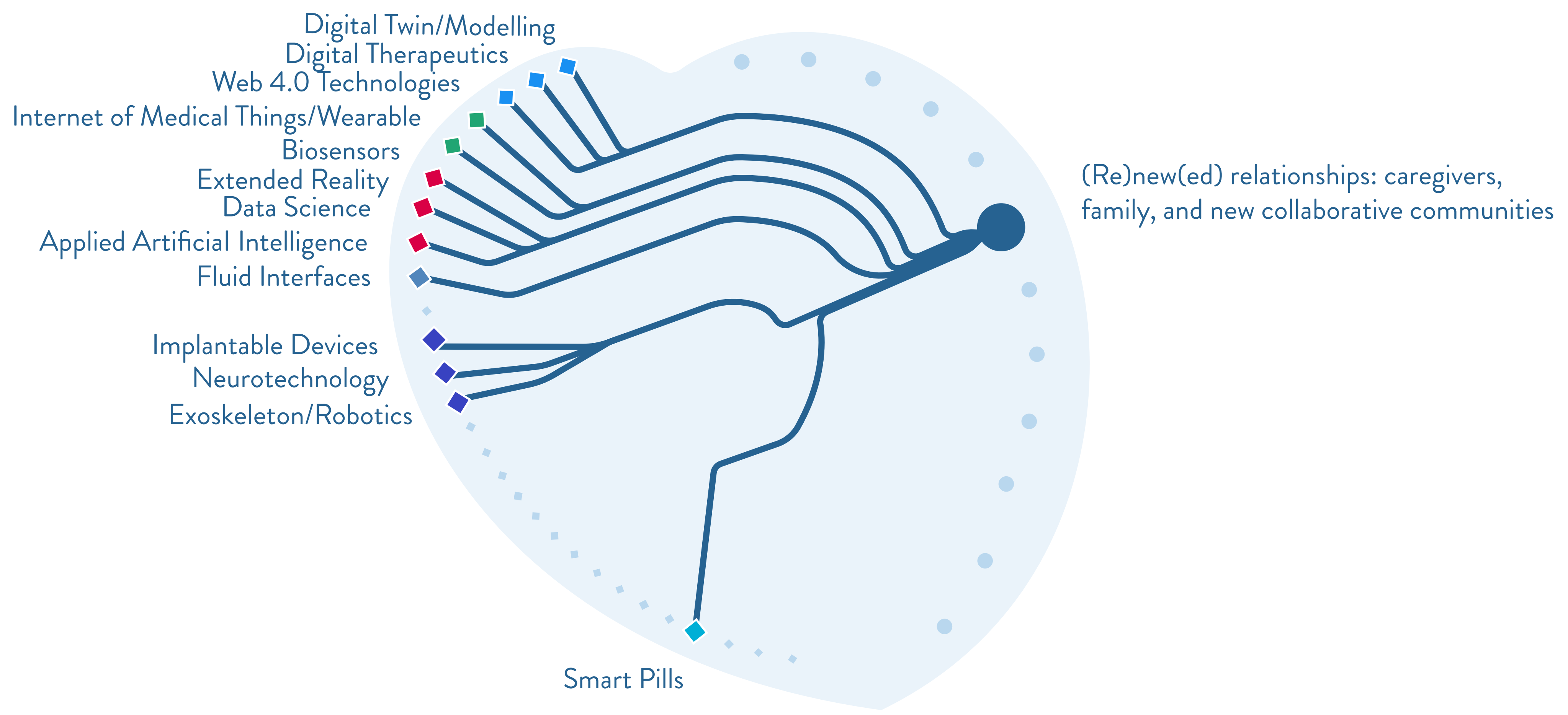
(RE)NEW(ED) RELATIONSHIPS: CAREGIVERS, FAMILY, AND NEW COLLABORATIVE COMMUNITIES

Caregivers will benefit from the integration of smart technologies and new interfaces, enabling them to receive **24/7 remote support** in their daily routines and reducing the likelihood of emergency situations. However, the successful implementation of such a system necessitates the establishment of an **in-home care network** and the availability of qualified personnel. Beyond the integration of human and digital, it is also essential to **reimagine communities and social structures**, particularly for the elderly, ensuring they receive necessary monitoring and companionship without ever feeling isolated or abandoned.

While the pursuit of life extension is commendable, it does not necessarily imply a guarantee of **active longevity and healthy ageing**. Therefore, the creation of meeting places and the adoption of co-housing models represent a future **economic opportunity and a medical functionality**, also to avoid the socio-affective isolation. By redefining the role of the elderly within the family unit, we can leverage their wisdom and experience them as a **cultural and economic asset** while fostering interconnected networks that promote mutual support and overall well-being.

Technologies



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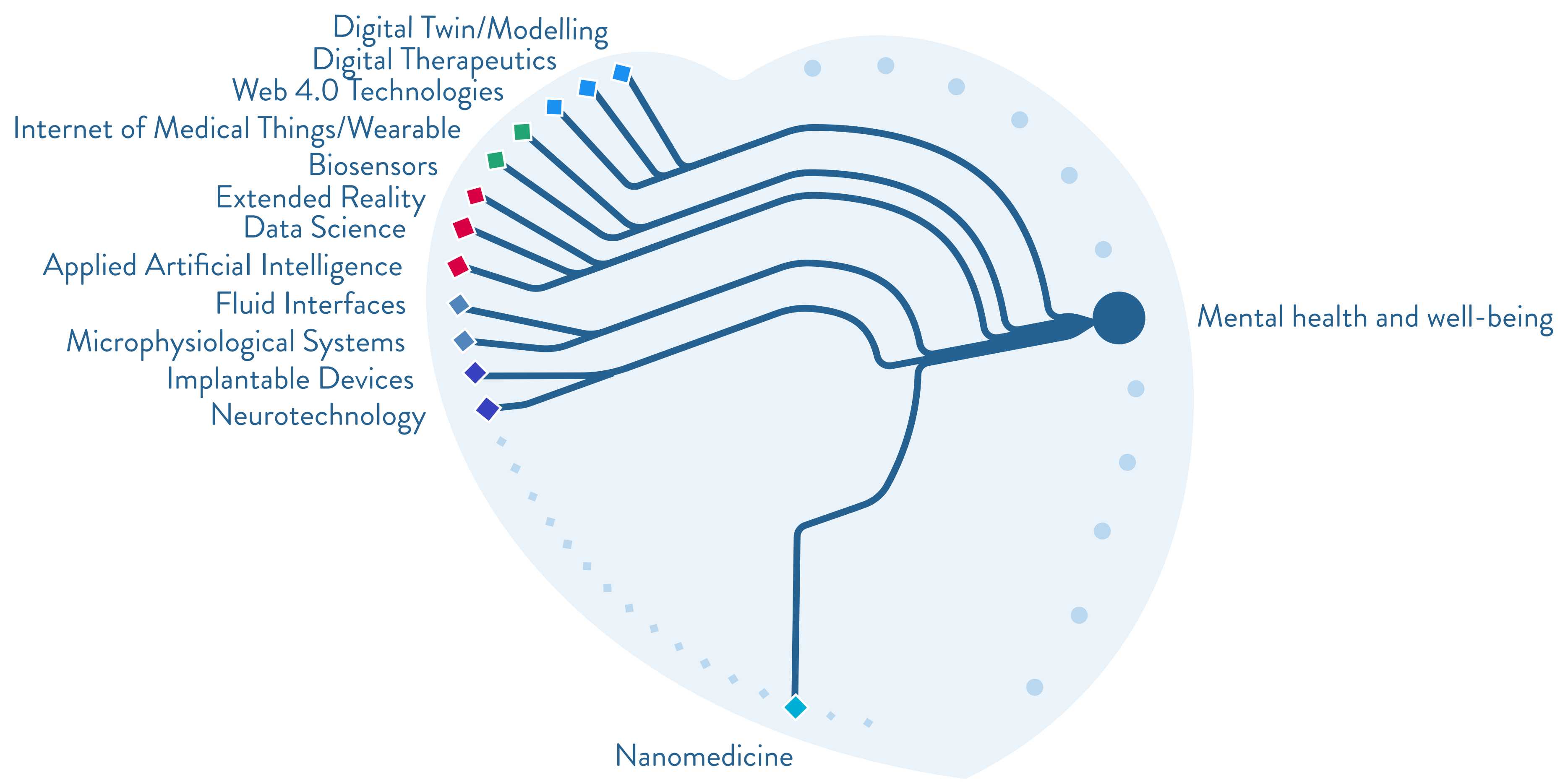
MENTAL HEALTH AND WELL-BEING

In recent years, cases of frailty and help requests have significantly increased. As a result, mental health is progressively gaining importance: it is not possible to separate **physical well-being** from **psychological and mental well-being**. Indeed, the World Health Organization recently introduced the importance of the perception of being healthy as a condition that improves health itself.

The focus on **more awareness and consciousness** of one's physical health status might cause stress and/or hypochondria, and technologies could exacerbate anxiety, leading to hazardous behaviours and an increased medicalisation of life. Early prediction/diagnosis of non-curable diseases could create a psychological burden such that the benefits of early-stage prediction or diagnosis might become a limitation.

The challenge ahead is to be able to educate towards the right balance between **awareness and concern**.

Technologies



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HEALTHCARE SUSTAINABILITY

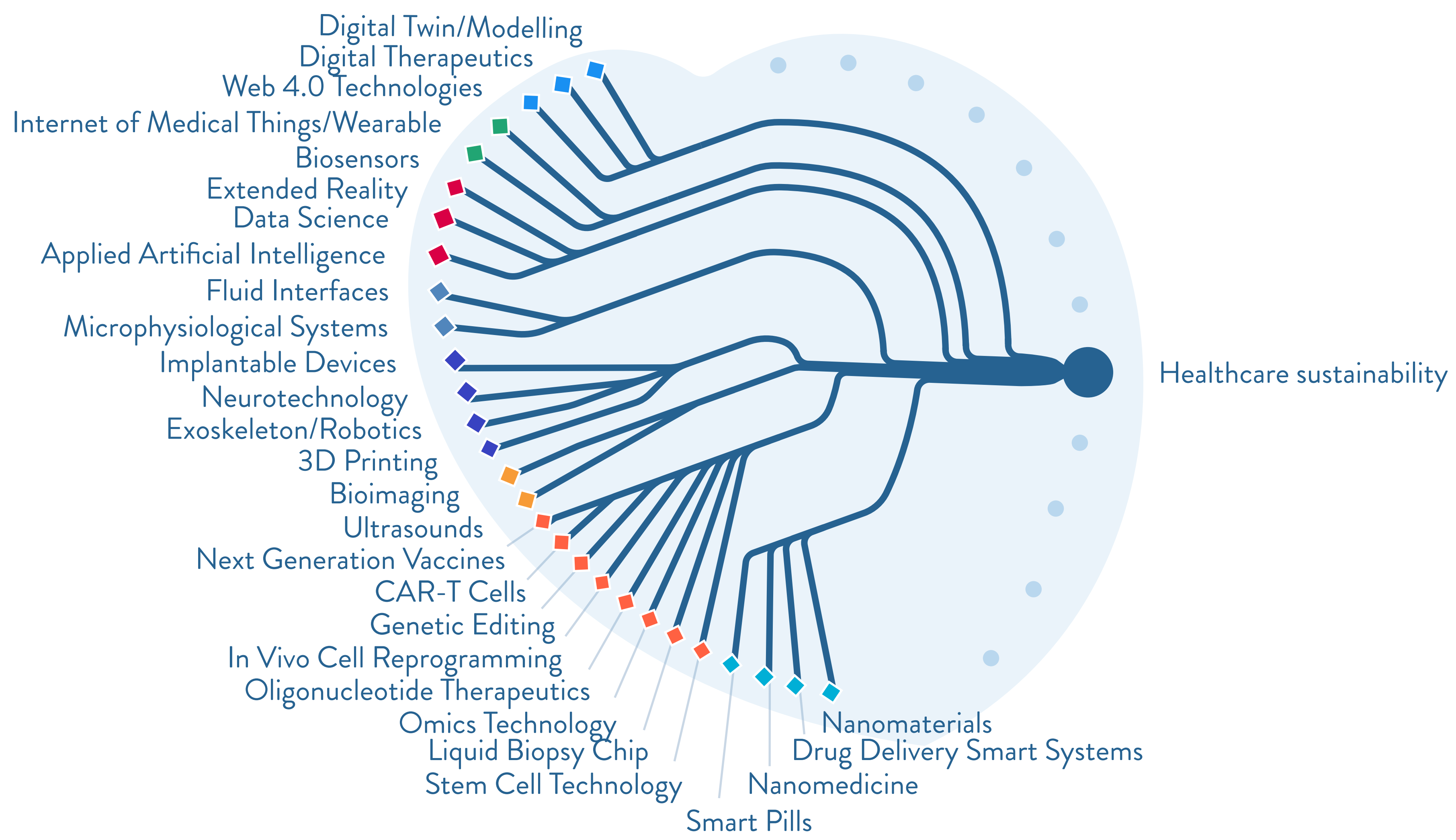
Sustainability is today paramount, and it will be even more so in the future. In the explored future scenarios, disruptive technologies promise to change the health panorama, yet they will need to be sustainable from many perspectives.

Economic costs are a primary matter and the accessibility of **prevention and monitoring** technologies, as an example, will determine how, if, and when the paradigm shift from care to prevention will take place. Similarly, AI economic and environmental costs are an important issue for the technology to be exploitable as envisioned.

The economical perspectives open debates on the public/private healthcare dilemma, acknowledging the importance of **public healthcare**, yet being aware that an entirely public model might not be sustainable.

Indeed, in the healthcare context sustainability goes beyond the economic sphere, reaching the **environmental and cultural dimensions**. Sustainability is also heavily related to demographic changes, ageing population, migrations, the rise of chronic diseases, and new pandemics, posing the attention on identifying which population groups can be affected most by the **sustainability impact**.

Technologies



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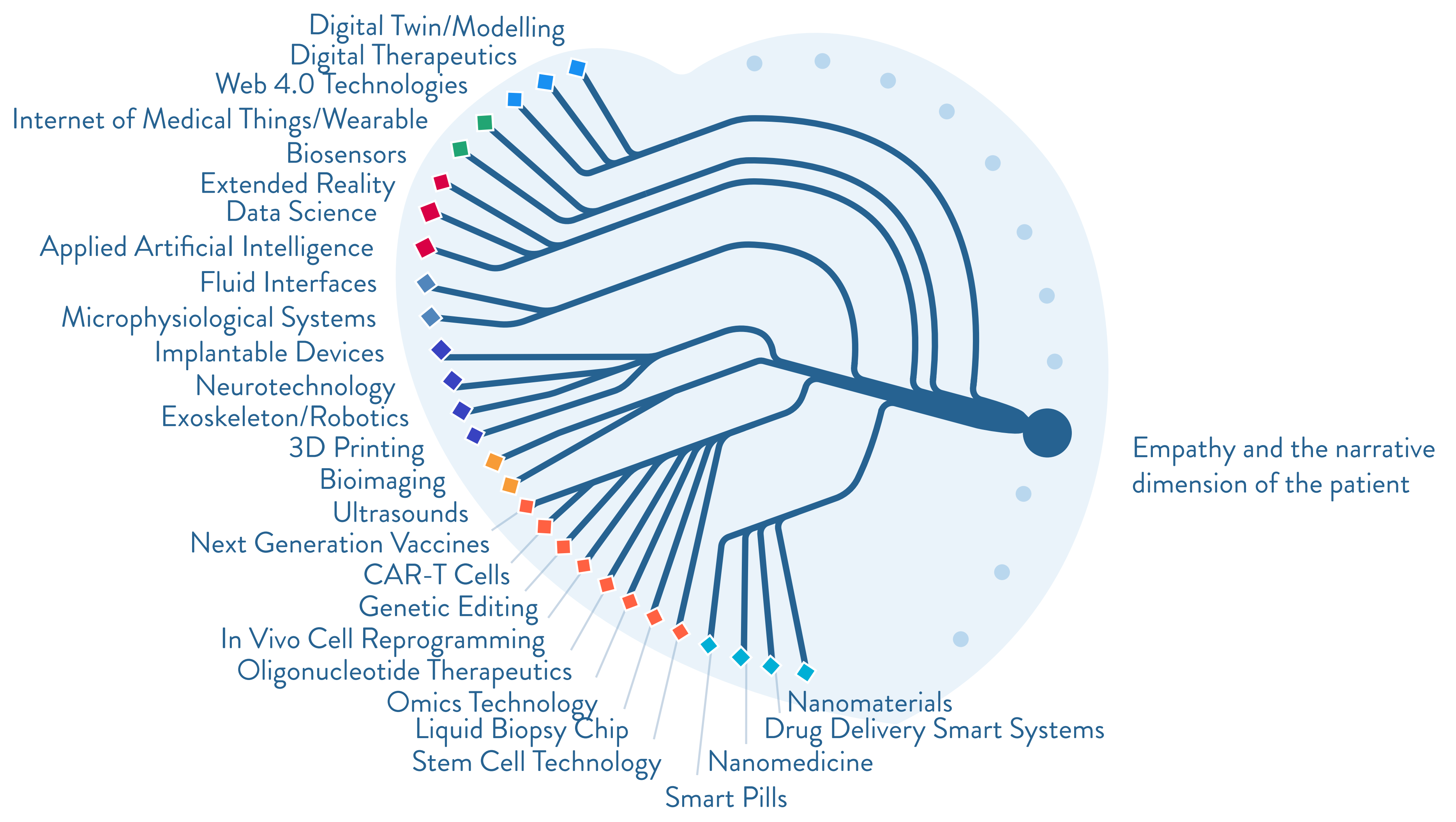
EMPATHY AND THE NARRATIVE DIMENSION OF THE PATIENT

The **General Practitioner** is a pivotal figure in the future of personal health: the physician who has a **holistic view** of the patient and knows the patient's personal history. General Practitioners will be **supported by the newest technologies**, for tasks that can be automated, extended, and supervised, thus reducing the workload and allowing physicians to create relationships with every patient.

Future perspectives on the evolution of the General Practitioner figure also concern **the new professional profiles** that will flank those already known: an example is the technologist who will oversee the operation of biomedical devices in support of data collection and monitoring. Engineers and computer scientists will also be professionals playing a key role when it comes to personal health (possibly supported by Artificial Intelligence and innovative technologies).

Technologies



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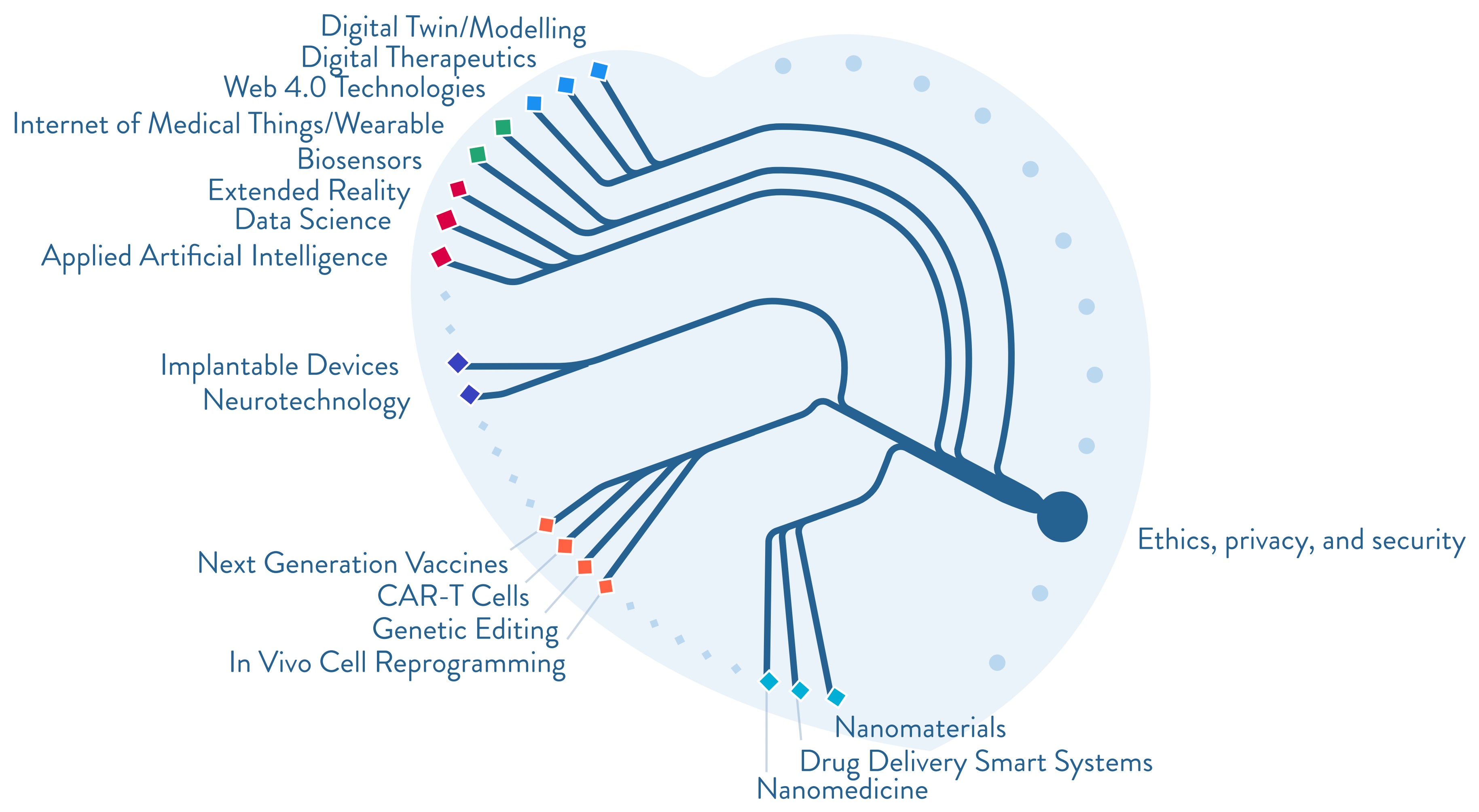
ETHICS, PRIVACY, AND SECURITY

The evolution of technologies raises questions regarding their **sustainability**, the generation/creation of knowledge, the role of the **physician**, and emerging **rights and discriminations**. Ethical questions in health, healthcare and public health include different topics at both individual and collective levels.

The growth of data and its use raises questions about privacy and the handling of non-medical data. With the increasing volume of data and their interoperability, ensuring data security becomes a critical task.

In addition to the issue of **dual-use technologies**, ethical dilemmas pervade several key areas including technological devices and Artificial Intelligence, future health professions, the right to be forgotten and the non-tracking of data, the attribution of responsibility, risks and errors, the cultural sustainability of new technologies, the limits and potential of research, and the perspective of medicine about pandemics, future diseases, and deaths.

Technologies



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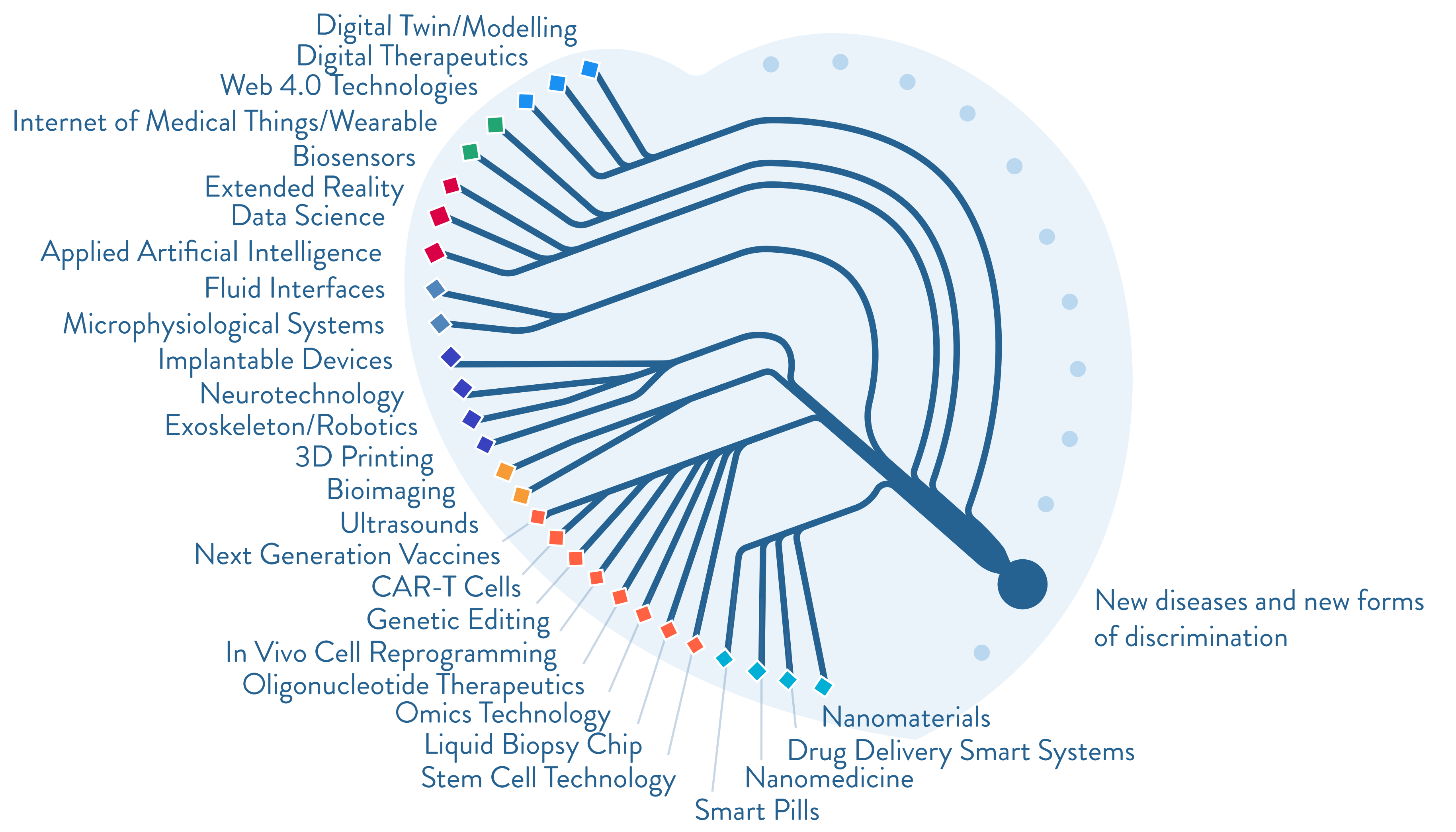
NEW DISEASES AND NEW FORMS OF DISCRIMINATION

As advancements in knowledge and technology are enhancing prevention and more effective treatment of today's serious and incurable diseases, such as chronic and rare ones, **new diseases are expected to emerge**. These may arise due to changes in climate and pollution, migrations, dietary habits, and lifestyles.

Additionally, there is concern among scientists regarding unknown viral threats, prompting research into potential defence mechanisms against a hypothetical future "Disease X" - an unidentified pathogen that could trigger a severe global epidemic or pandemic.

The widespread adoption of technologies can intensify **discriminations and inequalities, widening the gap** between those with access to healthcare and technology and those without. Moreover, in a resource-constrained future, discrimination may also impact diseases prioritisation, with rare or geographically isolated diseases potentially receiving less funding and attention.

Technologies



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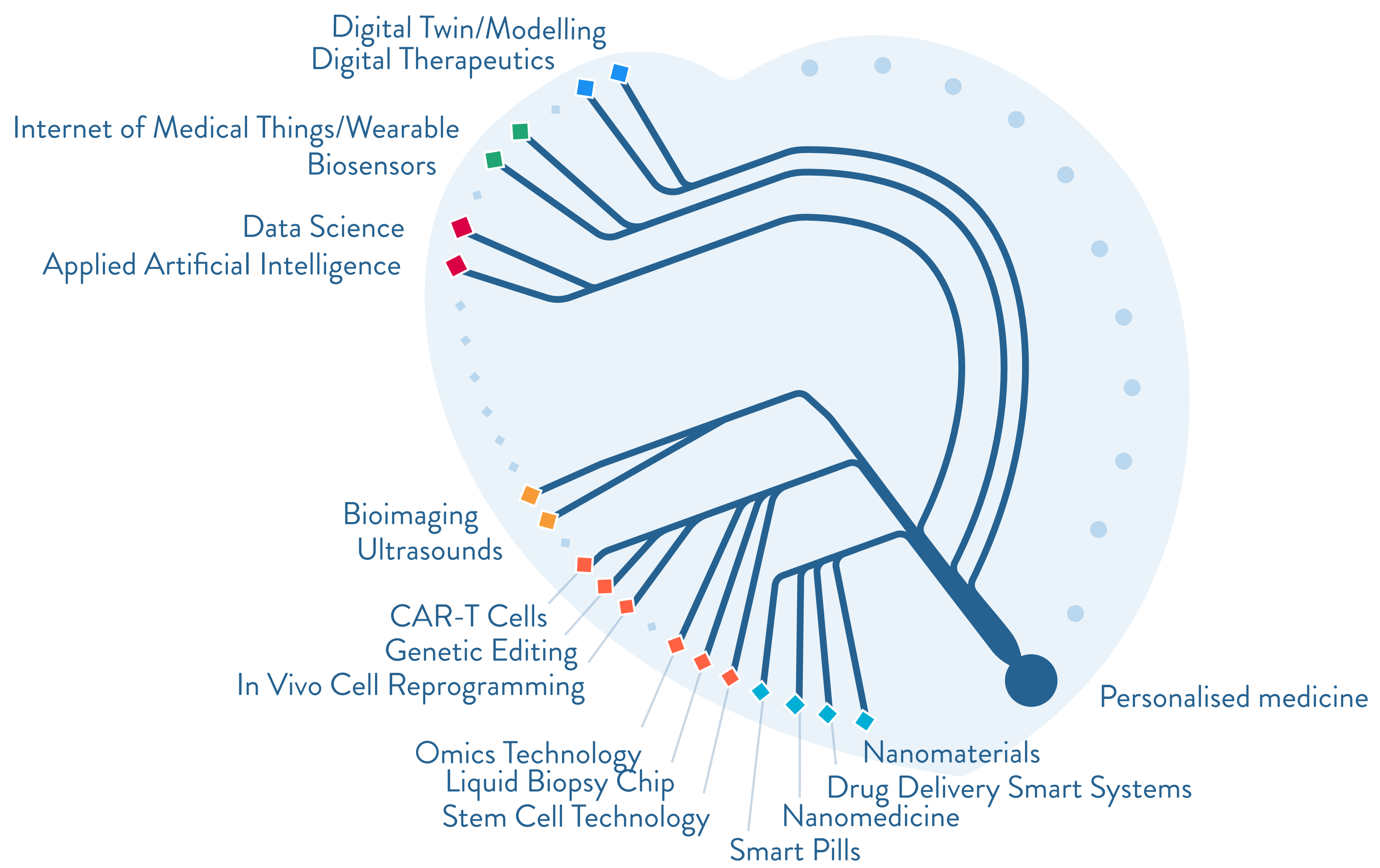
PERSONALISED MEDICINE

Personalisation has reached various stages linked to individual health, covering all phases, **from prevention to diagnosis, from treatment to rehabilitation**. Using the latest technologies, there are personalised prevention plans, personal interventions to improve outcomes and reduce complications, reduction of unnecessary interventions and improved scheduling, personalised treatment, and rehabilitation paths.

At the pharmacological level, it is also possible to orient drug administration based on the characteristics of every person by adopting different protocols.

The goal of the medicine of the future is to guarantee **healthy living conditions and personalised care** by acting not only on genetic predispositions but also on other indicators (for this reason information programmes on the adoption of healthy lifestyles and individualised plans are widespread).

Technologies



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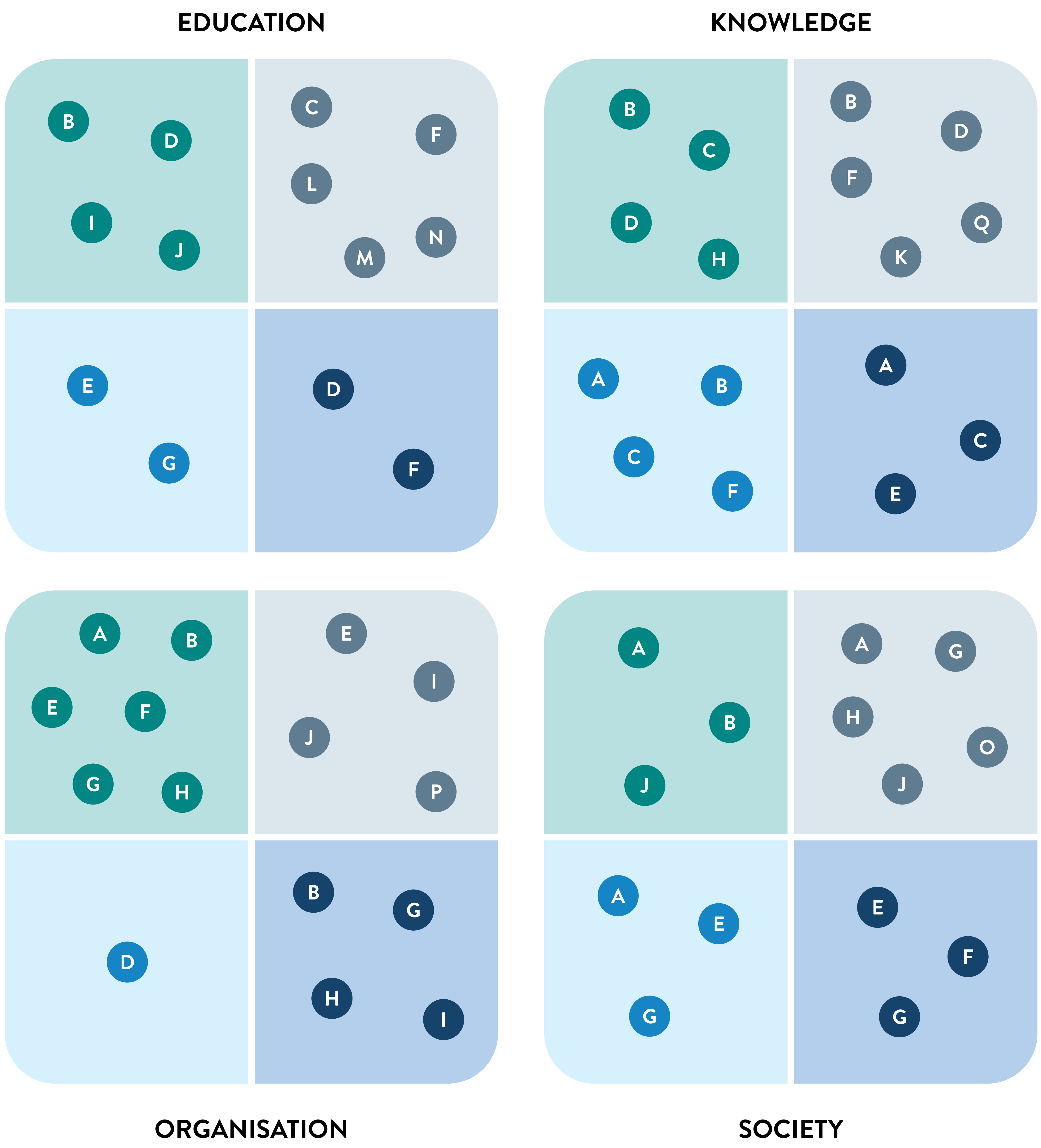
Opportunities, Requirements, Risks, and Impacts



The exploration of what the future of human health might look like in 2040 and the conversations on possible scenarios were characterised by several recurrent emerging factors. These factors are associated with the technologies and their transformative potentials, enablers, and barriers, as well as their prospective effects.

We clustered several elements that emerged from the discussions within four major perspectives: education, knowledge, organisation, and society.

OPPORTUNITIES

- A Autonomy and independence beyond old age
- B Awareness and responsibility
- C Data-driven medicine
- D Expansion of knowledge
- E Immediate disease detection
- F In-home care
- G National Health Service improvement and rationalisation
- H New data-collection technologies
- I New professional figures
- J Positive attitude towards health-related matters

REQUIREMENTS

- A Access to personal data
- B Data accuracy and quality
- C Data/knowledge interoperability
- D Infrastructures
- E New risk factors related to constant monitoring
- F Population engagement
- G Widespread health-related education

RISKS

- A Commercial/economic pressure for technology pervasiveness
- B Data/knowledge privatisation
- C Data dual use
- D Data islands (heterogeneous and non-interoperable data)
- E Decreased efforts to address specific population groups' diseases
- F Digital divide/inequity growth
- G Digital surveillance
- H Insurance companies polarisation
- I Over-diagnosis and over-treatment
- J Private market-driven priorities
- K Profit-oriented research
- L Psychological stress/hypochondria
- M Self-diagnosis/self-cure
- N Socio-affective isolation
- O Technology refusal due to complexity
- P Unsustainable (technological) costs
- Q Unvalidated/uninterpreted data use

IMPACTS

- A Collected/managed data exponential growth
- B International uniformity in data use
- C Limited attention to social risk factors
- D New markets for data
- E Population engagement
- F Prediction/prevention costs growth
- G Reduced burden over healthcare facilities
- H Simplification of caregivers' role
- I Treatment costs reduction

Conclusions and Next Steps

Groundbreaking technologies are fundamentally reshaping individual healthcare. Increasing awareness and monitoring of healthy lifestyle decisions among individuals will change healthcare. Moreover, the dynamics of doctor-patient relationships are evolving through the incorporation of AI assistance. Physicians will be enabled to focus on the narrative dimension of patient care, supported by technologists capable of collecting and analysing vast amounts of data with increasingly sophisticated models. These technological advancements enable a holistic assessment of the patient's mental and physical health.

The great absentee, however, is the analysis of sustainability. Indeed, it is unclear whether these biomedical devices will be economically and ecologically available to everyone or only to a part of the world's population. Similarly, the cost of managing an increasing amount of data is unclear. Certainly, personalised medicine could improve prediction and prevention, reduce treatment costs, and invest in a quality of life well into old age.

In our journey through the future of health, this activity on personal health is only a first step. Although some of its insights extend to broader scenarios, the second activity will specifically address the community/system level: healthcare systems as we know them are undergoing radical transformations, where remote access to physicians, care, and services is rapidly increasing. Finally, the third activity will focus on the ecosystem level, encompassing the relationship between environmental and human health within the One-Health perspective.

More information available at: https://www.foresight.polimi.it/health/

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Participants to interviews and workshops are listed below. We thank them for their invaluable contributions and insights.

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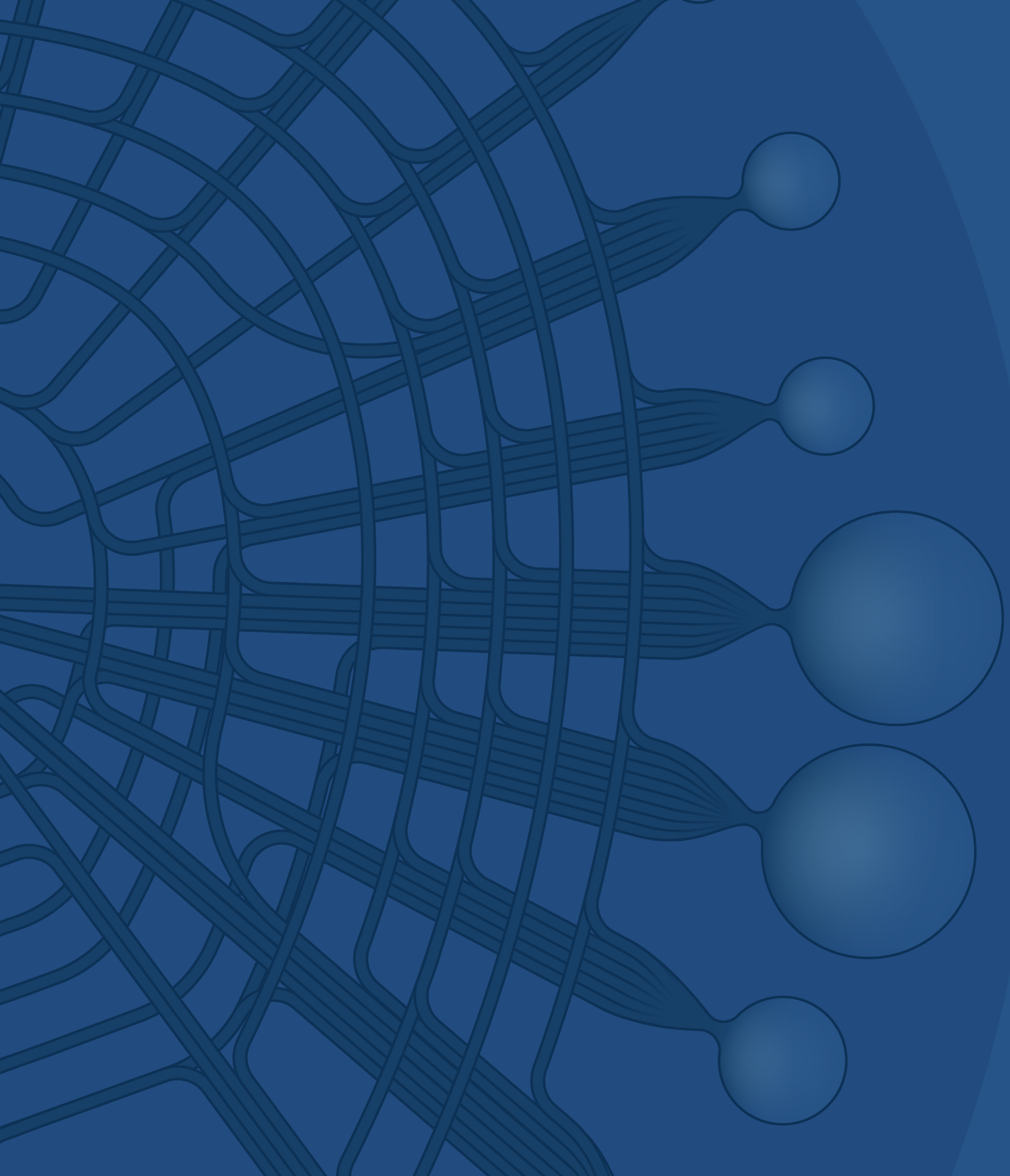

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