Tech Giants in Healthcare

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TECH GIANTS IN HEALTHCARE

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EXECUTIVE SUMMARY

Tech giants are the primary forces driving digital transformation forward. In the medium to long run these firms, which can exercise exceptional market power, may be able to profoundly change the range of healthcare services offered in the marketplace, and indeed reshape the nature of existing healthcare systems. Particularly in case of publicly financed systems that are organized by sectors[1] and based on the principle of solidarity, this could lead to a paradigm shift in the way healthcare is shaped, delivered and consumed. The focus of care is shifting from traditional therapy to prediction, prevention and precision medicine. The boundaries between sectors are becoming more permeable, and ultimately dissolve in favor of patient-centered care. In addition, research and day-to-day healthcare are moving closer together, creating opportunities to build learning healthcare systems.

In this study, we use the term "tech giants" to refer to technology companies that are unique regarding their expertise in digital technologies, and the great extent of financial, human and technical resources at their disposal. In most cases, these companies initially established themselves in another area of business activity. By entering the healthcare market, they are pursuing both their own economic interests and – according to their own statements – the goal of using digital innovations to significantly improve health(-care) behavior and healthcare provision, and thus individual and public health.

The healthcare products and applications developed by tech giants are mostly based on huge amounts of data drawn from different areas of life, which they evaluate using so-called artificial intelligence (AI) tools to assess the presence of diseases; calculate risks and expected needs; identify and develop diagnostic, therapeutic and preventive measures; and connect and optimize care processes. In collecting the data needed by such systems, the companies largely use their own products and services. Many such products, such as smartphones, are widely used and primarily serve purposes other than health, though companies additionally develop their own new devices and systems for health care applications. They also engage in health research, very often in cooperative ventures of various kinds. In some cases, they operate hospitals, networked care systems or health insurance companies.

All of this activity is changing the digital (health) skills required of those who work in health care, creating new job profiles and professional responsibilities. The increasing importance of data and technological know-how is giving the tech giants a market position that, in many senses, resembles a traditional monopoly. In this role, they have broad influence over other actors' market access, but also

1 In some health care systems, the provision of health care services in the in- and outpatient sectors as well as rehabilitative care can have major systematic differences. For example, the German healthcare system generally distinguishes between in-patient clinical and out-patient ambulatory care as well as in- and outpatient rehabilitative care. Each of these sectors follow varying rules for the administration and reimbursement of medical care, leading to sectoral boundaries in the way healthcare can be obtained.

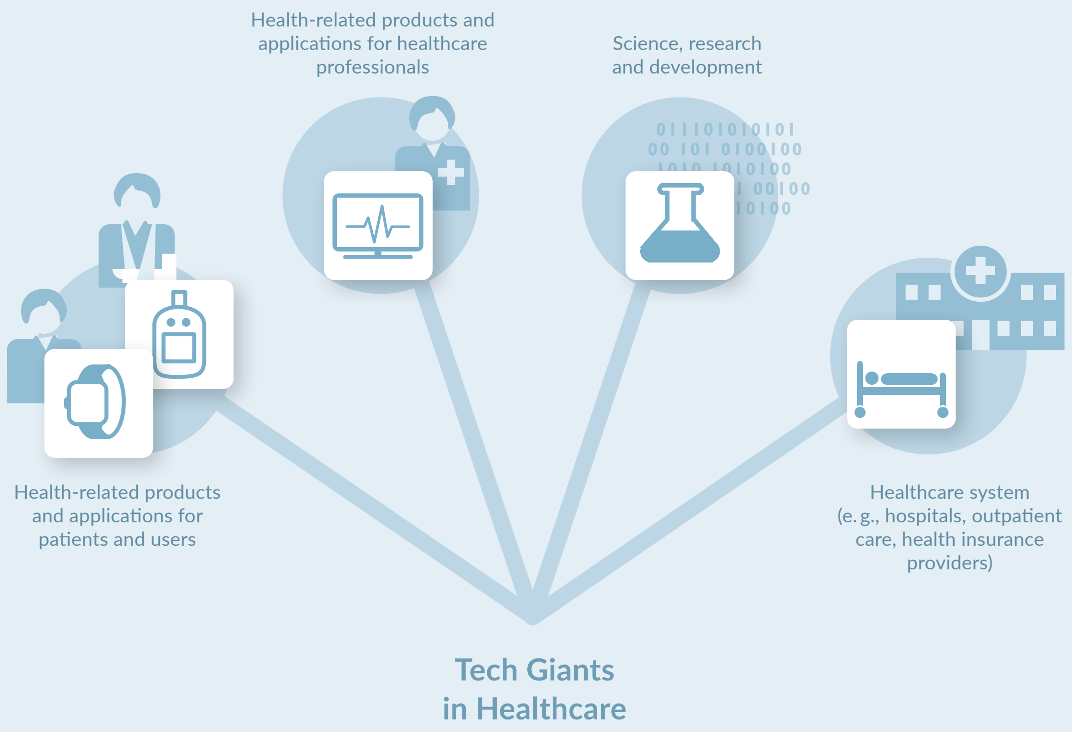


FIGURE 1: **Areas of application examined**
Source: Authors, Bertelsmann Stiftung

have, de facto, the authority to shape individual and societal expectations and demands, effectively determining the boundaries of what is deemed possible in healthcare. Power of this kind can erode the freedom of choice within a social market economy, and undermine the degree to which the social framework itself is democratically determined.

Thus, when viewed in terms of high-level ethical principles and values, the tech giants' activities in the healthcare sector present both significant opportunities and risks. For example, they provide modern technologies that can be used to promote health and self-determination, improve access to medical care, protect privacy and optimize care processes. At the same time, however, there are significant risks with regard to privacy, protection against discrimination, and even health and self-determination. Tech giants in the United States, Europe and Asia differ with regard to the type and scope of their impact.

This study features a number of examples to highlight the tech giants' diverse activities in the healthcare sector. In addition, it presents, as an overwiew, an ethical analysis of some particularly relevant change processes being driven in large part by tech giants, and concludes with eight recommendations for productively engaging with tech giants to improve healthcare while avoiding ethically significant risks.

CONTENTS

ACRONYMS AND ABBREVIATIONS

AADE American Association of Diabetes Educators
AAL Ambient Assisted Living
ACC American College of Cardiology
ACS American Cancer Society
ADA American Diabetes Association
AGG Allgemeines Gleichbehandlungsgesetz; General Act on Equal Treatment
AGI artificial general intelligence
AHA American Heart Association
AHS Apple Heart Study
AI artificial intelligence
AIMIS AI Medical Innovation System
Amwell American Well
ANI artificial narrow intelligence
API application programming interface
AR augmented reality
AS adaptor set
ASR automatic speech recognition
AWS Amazon Web Services
B2B business-to-business
BDI Initiative des Bundesverbands der Deutschen Industrie e. V.; The Federation of German Industries
BfArM Bundesamt für Arzneimittel und Medizinprodukte; Federal Institute for Drugs and Medical Devices
BGI Beijing Genomics Institute
BMBF Bundesministerium für Bildung und Forschung; Federal Ministry of Education and Research
BRAC Bangladesh Rural Advancement Committee
BWA Burrows-Wheeler Aligner
BWEL Breast Cancer Weight Loss Study
BWH Boston's Brigham and Women's Hospital
BWH Brigham and Women's Hospital
C2C customer to customer
CBICA Computing and Analytics
CDC Center for Disease Control and Prevention
CDHI Center for Digital Health Innovation
CDSS clinical decision support system(s)
CEO Chief Executive Officer
CFR Charter of Fundamental Human Rights of the European Union
CHD coronary heart disease
CHLA Children's Hospital Los Angeles
CMO Chief Medical Officer
CT computer tomography
CVC corporate venture capital
CZ Biohub Chan Zuckerberg Biohub
CZI Chan Zuckerberg Initiative, LLC
DAX Dragon Ambient eXperience
DER Deutscher Ethikrat; German Ethics Council
DFG Deutsche Forschungsgemeinschaft; German Research Foundation
DGQ Deutsche Gesellschaft für Qualität; German Association for Quality
DHSC Department of Health and Social Care UK
DiGA Digitale Gesundheitsanwendung; Digital Health Applications
DKG Deutsche Krankenhausgesellschaft e.V.; The German Hospital Federation
DL deep learning
DLT distributed ledger technology
dpa Deutsche Presse-Agentur; German Press Agency
DVG Digitale-Versorgung-Gesetz; Digital Healthcare Act
DWP Diabetes Wellness Program
EbM evidence-based medicine
EC European Commission
ECG electrocardiogram
ECHR European Court of Human Rights
EEG electroencephalography
e-health / eHealth electronic health
EHR electronic health record(s)
EP European Parliament
eSIm embedded subscriber identity module
EU European Union
EU-GDPR European General Data Protection Regulation
FAA Federal Aviation Administration
FAIR Facebook AI Research
FAZ Frankfurter Allgemeine Zeitung
FDA U.S. Food and Drug Administration
FDP Freie Demokratische Partei; Free Democratic Party
FHIR Fast Healthcare Interoperability Resources
Fred Hutch Fred Hutchinson Cancer Research Center
GAFAM Google, Amazon, Meta (formerly Facebook), Apple, Microsoft
GATK genome analysis toolkit
GBE Gesundheitsberichterstattung des Bundes; Information System of the Federal Health Monitoring
GDP gross domestic product

GE General Electric
GG Grundgesetz; Basic Law
GHA German Health Alliance
GHP German Health Partnership
GKV Gesetzliche Krankenversicherung; statutory health insurance
GMCC Global MediXchange for Combating COVID-19
GPS Global Positioning System
GPU graphics processing unit(s)
CFR Charter of Fundamental Human Rights of the European Union
GSK GlaxoSmithKline
GV Google Venture
HIP Health Innovation Port
HIPAA Health Insurance Portability and Accountability Act
HITRUST Health Information Trust Alliance
HL7 Health Level Seven International
HPD Healthcare Provider Directory
IBM International Business Machine Cooperation
ICD10-CM International Classification of Diseases, Tenth Revision, Clinical Modification
ICT Information and Communication Technology
ICU Intensive Care Unit
IIG Institute of Immunology and Genetics
iOS iPhone Operation System
IoT Internet of Things
IRIS Intelligent Retinal Imaging Systems
IT information technology
ITU International Telecommunication Union
Leopoldina Deutsche Akademie der Naturforscher Leopoldina e. V.
MDR Medical Device Regulation
m-health mobile health
MH-Guide Molecular Health Guide™
MIC Medical Informatics Corporation
MITeC Medical Innovation and Technology expert Center
ML machine learning
MMAR Clara Train Medical Model Archives Modification
MoU memorandum of understanding
MRI magnetic resonance imaging
MS multiple sclerosis
NASA National Aeronautics and Space Administration
NGO non-governmental organization
NGS next-generation-sequencing
NIEHS National Institute of Environmental Health Sciences
NLM National Library of Medicine
NLP natural language processing
NLU natural language understanding
NPO non-profit organization
NYU New York University
OECD Organisation for Economic Co-operation and Development
OTC over-the-counter
PAI Partnership on AI
PATH Program for Appropriate Technology in Health
PCOS polycystic ovary syndrome
PDA personal digital assistant(s)
PET positron emission tomography
PHR personal health record(s)
PKV Private Krankenversicherung; private health insurance
POCT point-of-care-testing
PPP public-private partnership
QS quantified self
RCT randomized controlled trial
SAP Systemanalyse Programmentwicklung; System Analysis Program Development
SAP HANA SAP High Performance Analytics Appliance
SDK software development kit
SGB German Social Code
sNFL serum neurofilament light chain
SPD Sozialdemokratische Partei Deutschlands; Social Democratic Party
StMGP Bavarian State Ministry of Health and Care
SVR Sachverständigenrat zur Begutachtung der Entwicklung im Gesundheitswesen; German Council of Health Experts
TI telematics infrastructure
TS terminology server
UCL University College London
UCLA Health University of California Health Department, Los Angeles
UCSF University of California, San Francisco
UDHR United Nations Declaration on Human Rights
UK NHS United Kingdom National Health Service
UMCU University Medical Center Utrecht
VR virtual reality
Wearable(s) wearable electronic device(s)
WHO World Health Organization
WKO Wirtschaftskammer Österreichs; Austrian Economic Chambers
WW Weight Watchers

1 INTRODUCTION

1.1 STARTING POINT

It is impossible to imagine our world today without digital transformation. The digitalization of products, processes and structures is having a sweeping impact across all areas of individual and social life.

In the healthcare sector too,[2] the extent of digital data collection and processing is growing exponentially, and digital trends and technologies[3] are increasingly converging. Both Topol (2013) and Hahn and Schreiber (2018) speak of a "super-convergence" that is laying the foundations for a new approach to medicine. The German healthcare system has only just begun to navigate its way

2 "A state's healthcare system includes all regulations, measures, technical resources, facilities, professions and persons that have the goal of promoting, maintaining, establishing or restoring the health of the population. Accordingly, the healthcare system in the broader sense encompasses all activities, both public and private, performed either by professionals or laypeople, that center on health" (Labisch and Paul 1998: 123).

3 Both the current discourse and the recent literature include the terms "digital health" and "e-health." In this regard, digital health can be understood as "the use of modern ICT [information and communication technologies] in healthcare to increase quality and efficiency, and to heighten the focus on patient needs" (Angerer et al. 2019: 6). The category of e-health (electronic health) encompasses "electronically supported activities and systems in healthcare that collect, make available, and/or evaluate patient data and other medical information remotely, using techniques that are not yet widely regarded as standard" (Matusiewicz and Thielscher 2017). This consequently includes telematics and telemedicine (e.g., telediagnostics and teletherapy). In Germany, the Digital Healthcare Act (DVG) (Gesetz für eine bessere Versorgung durch Digitalisierung und Innovation, adopted on Dec. 9, 2019, BGBl. I: 2562) sets the goal of gradually networking all actors and institutions in the country's healthcare system via a secure telematics infrastructure (TI). We note in passing that it is not currently possible to draw a clear distinction between digital health and e-health, and that the terms are used inconsistently and sometimes synonymously. According to the WHO (2011) definition of m-health (mobile health), this is an aspect of e-health that has not been uniformly defined to date. For the purposes of that organization's Second Global Survey on E-health, m-health was defined as "medical and public health practice[s] supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices" (European Commission 2014: 3). "This includes applications (...) such as lifestyle and health apps that can be networked with medical devices or with sensors (e.g., in wristbands or watches), as well as personal notification or assistant systems, health information and medication reminders delivered via SMS, and wirelessly delivered telemedicine services" (ibid.).

toward digital transformation.[4] Nonetheless, these developments have kindled great expectations regarding the ability of new medical practices to meet the demands of the future (Topol 2015).[5]

Given the healthcare sector's considerable economic importance,[6,7] it should come as little surprise that digital transformation in the sector is increasingly driven by tech giants that previously had little to do with healthcare, but do have considerable experience developing and using information and communication technologies (ICT) in various areas of life. Apple CEO Tim Cook has even mused about the company looking back one day and realizing that its greatest contribution to humanity will have been in the area of healthcare (Pearl 2019).

As they enter this field, tech giants are pursuing a variety of individual business models, for instance by expanding the features and applications of existing proprietary products and services (e. g., wearables), investing in cloud technologies, or introducing private services that extend beyond those offered in the publicly regulated healthcare system. These offerings may be centered on science, research and development tasks (e. g., AI and healthcare cloud computing); lifestyle (e. g., mobile apps); or healthcare interventions directed toward specific diseases. Strategically, technology companies are seeking to enter the healthcare market[8] via partnerships, collaborations and alliances, as well as by acquiring or investing in startup companies (Kindermann and Lindemann 2018; Yildirim et al. 2016).

Tech giants still play a relatively insignificant role in Germany's healthcare sector. However, they already engage in a wide spectrum of activities internationally, ranging from offering and administering medical care (including the construction of hospitals) and the financing of healthcare services (including health insurance) to facilitating the digital exchange of information between various actors, devices and structures.

In the long run, tech giants are likely to carve out strong positions for themselves in the healthcare sector. In a survey conducted by the Roland Berger management consultancy, 61 % of the experts polled said they were convinced that "large tech corporations will be an integral part of the healthcare system by 2025" (Choueiri et al. 2019: 10).

4 "The term 'digital transformation' refers to a significant body of active changes in everyday life, the economy and society due to the use of digital technologies and techniques, as well as their effects" (Pousttchi 2017).

5 For example, the implementation of a personalized, preventive, predictive and participatory healthcare system – so-called P4 medicine – would serve as an exemplary illustration of such changes (Flores et al. 2013).

6 Healthcare spending in Germany totaled € 410.8 billion in 2019. This was a 4.9 % rise compared to 2018, roughly in line with the rate of increase in previous years. Healthcare spending accounted for 11.9 % of Germany's gross domestic product (GDP) in 2019. Within this total healthcare expenditure, 56.7 % or € 233 billion was attributable to the statutory health insurance (SHI) system (Federal Statistical Office, April 6, 2021). Globally, healthcare spending totaled $ 8.5 trillion in 2019 (WHO 2021d).

7 According to management consultants Roland Berger GmbH, the digital health market is expected to grow to € 57 billion in Germany, € 232 billion in Europe as a whole and € 979 billion worldwide by 2025 (Choueiri et al. 2020: 7).

8 The term "healthcare market" refers to that area of the market in which halthcare services and products are the object of economic activity. It is divided in turn into the primary and secondary healthcare markets (Krimmel 2005). The former represents the exchange of traditional healthcare services and interactions between healthcare-provision structures. The services and products within this category are financed by private health insurance (PHI) plans and statutory health insurance (SHI) systems. The customer base within the primary healthcare market is made up of patients or persons undergoing treatment. The primary market is regulated by stricter legal frameworks than the secondary healthcare market (Damm et al. 2010: 1–3). The secondary healthcare market includes health-related services and products that are not covered by private insurance, statutory insurance programs or other public insurance entities; this includes items and services such as nutritional supplements, fitness courses and over-the-counter drugs. In this case, the customers are not exclusively people who are already ill. Rather, the focus is on preventive services, and on maintaining good health (ibid.; Krimmel 2005).

1.2 WHO ARE THESE TECH GIANTS?

The literature currently contains no clear definition or criteria indicating which technology companies should be identified as tech giants. The literature review performed for this study revealed that the terms "tech superstars," "tech corporations," "tech giants," "big tech," "online giants," "large digital companies" etc. are for the most part used synonymously.

Writers referring to tech giants often do so using the acronym GAFAM.[9] This refers to the technology companies Google LLC. (or for short,[10] simply Google; its parent company is Alphabet Holding Inc. (Alphabet)), Apple Inc. (Apple), Meta Platforms Inc. (Meta; formerly Facebook Inc.),[11] Amazon.com Inc. (Amazon) and Microsoft Corporation (Microsoft). Most of these U.S. companies are based in Silicon Valley, a region close to San Francisco known for its high number of technology companies and startups (Schulz 2018).

The five GAFAM companies were all among the top seven of the world's 100 most valuable corporations in 2021. Apple, with a market capitalization of € 2.515 trillion, led the list, followed by Microsoft at € 2.178 trillion and Alphabet at € 1.693 trillion (values as of December 2021) (Sommer 2021). According to reports in early 2022, Apple was the first publicly traded company to reach a market capitalization of $ 3 trillion. This is just under Germany's total annual economic output (tagesschau.de 2022). GAFAM companies together generate more than $ 800 billion in revenue annually, exceeding the output of Switzerland's economy, for example (2020 GDP: about $ 751.9 billion) (Sommer 2021; Desjardins 2019; WKO 2021).

The GAFAM companies also have a number of subsidiaries and spin-offs, such as the Alphabet subsidiaries Verily Life Sciences LLC (Verily; previously Google Life Sciences) and Calico Life Sciences LLC (Calico).

Silicon Valley has become the epitome and symbol of disruptive technologies and developments: "Not only because this is where the backbone of the technology industry is located, with the region's thousands of large companies and startups, but also because this is where the visionaries and utopians gather, the big dreamers and the reckless. Because here the money flows like nowhere else in the world – billions of dollars in venture capital every year. A perfect breeding ground for big ideas and world-changing developments" (Schulz 2018: 15).

9 Following Facebook's decision to rename itself as Meta, this acronym should now be GAMAM.

10 Within this study, the tech giants will generally be referred to by their short names.

11 Facebook announced that the company would be renamed Meta at the end of October 2021 (Meta 2021).

As new technological developments are tested, introduced but in many cases also ultimately discarded,[12,13] “vast quantities of investor money are effectively burned year after year” (Böttinger and Weiß 2019: 7). This allows even ideas whose success is far from certain to be tested.[14]

A number of other technology firms beyond the GAFAM companies, many originally from non-health fields, are also involved in healthcare. This list includes South Korea’s Samsung Group (Samsung); the U.S. companies Intel Corporation (Intel) and NVIDIA Corporation (NVIDIA); the Japanese technology company Sony Corporation (Sony); and the Chinese conglomerates Huawei Technologies Co. Limited (Huawei), Alibaba Group Holding Limited (Alibaba) and Tencent Holdings Limited (Tencent). Moreover, a number of other technology companies that are already well established in the healthcare sector are today moving increasingly into the digital healthcare market. This group includes SAP SE (SAP), Germany’s most valuable company (market capitalization: € 149 billion), and Siemens AG (Siemens) with its spin-off Siemens Healthineers. Siemens ranks only slightly lower than SAP among the world’s 100 most valuable corporations, with a market capitalization of € 125 billion (Sommer 2021). The Dutch Koninklijke Philips N.V. (Philips) and the U.S.-based International Business Machines (IBM) can also be placed in this category.

With this background in mind, we will in this study use the term “tech giants” to refer to technology companies that are unique regarding their digital technology expertise and resources, and which have vast financial means at their disposal. In most cases, they have achieved economic success and established a market position based on their activity in other areas of business. By entering the healthcare market, they are pursuing both their own economic interests and – according to their own statements – the goal of using digital innovations to significantly improve healthcare behavior and healthcare provision, and thus both individual and public health.

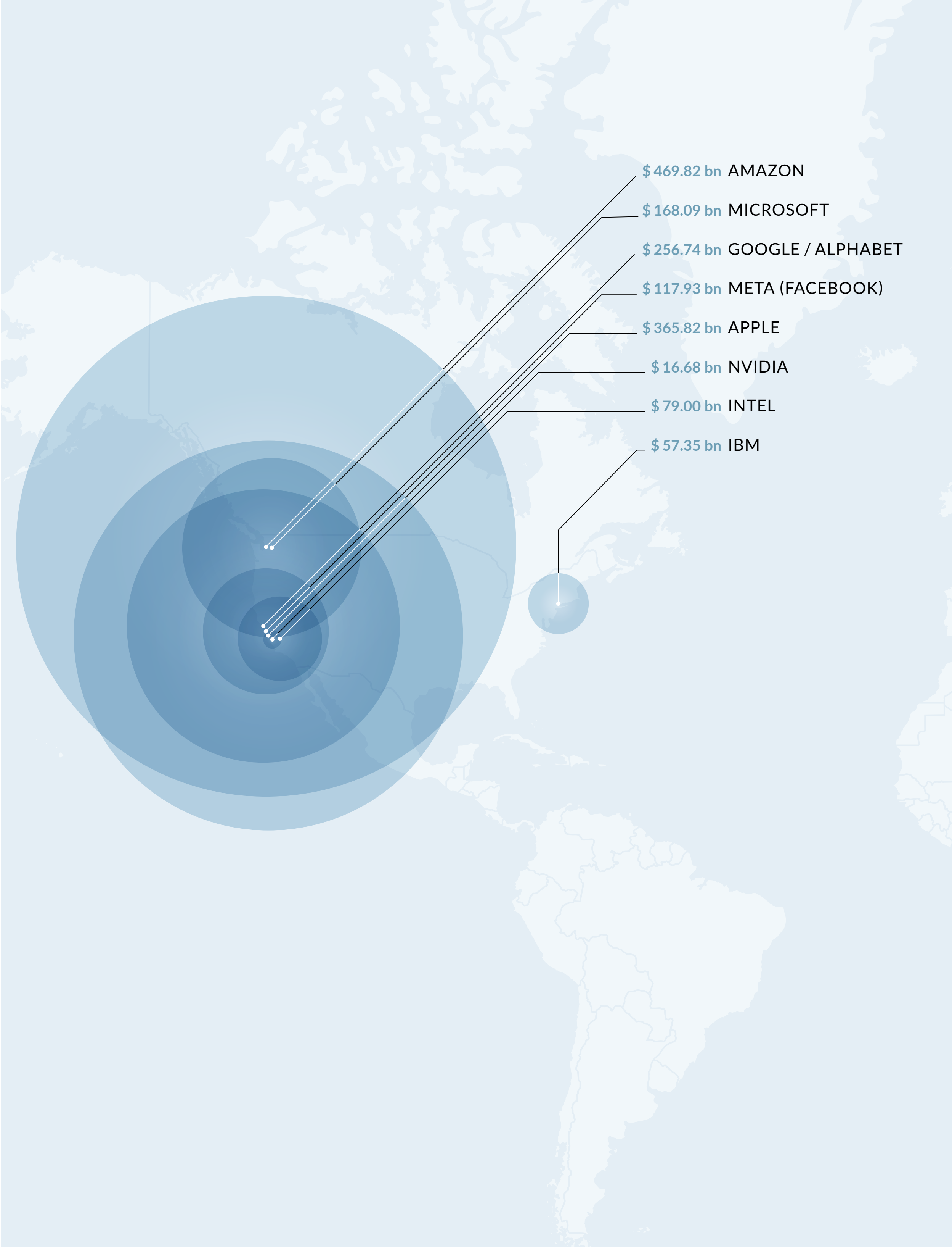
For the purposes of this study, we have selected 16 tech giants for review, with the goal of reflecting the full range of such companies’ activities, while also taking different world regions into account (→Table 1, Chapter 3). In late 2021, 13 of these tech giants were included in the ranking of the world’s 100 most valuable companies using the metric of market capitalization (Sommer 2021).

12 Google, for example, frequently discontinues new cost-intensive inventions and developments; a highly incomplete list of such products and services might include Google TV, Google+, Google Nexus, Picasa and Google Allo (Böttinger and White 2019; Ogden n. d.).

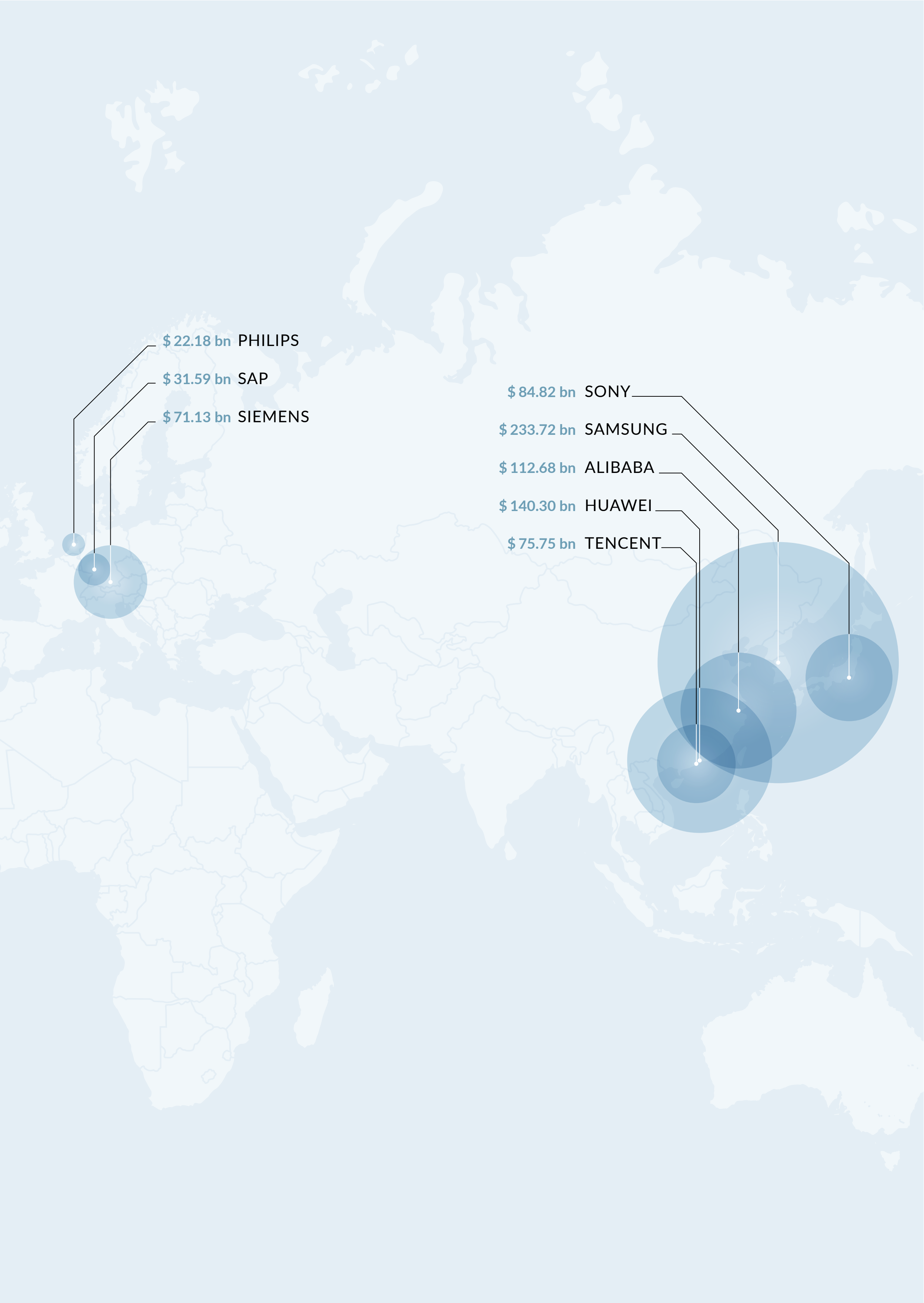
13 With its virtually unlimited capital, Alphabet has invested in a wide variety of so-called moonshot projects (→1.2), some of which have been discontinued in recent years. According to the company’s own statements, Alphabet has invested $ 2.3 billion in these projects since its inception, and has recorded a total of $ 24.3 billion in losses (Canales 2021).

14 Norman and Verganti (2014: 91–93) refer to research and development projects of this kind as “tinkering”: “When someone plays around with a product or a technology with no goal in mind – neither for enhancement of meaning, nor for practicality – we call it tinkering. Tinkering can lead to brilliant insights and new products but when such results happen, they are completely accidental.”

FIGURE 2: **Revenues for 16 tech giants (2020 / 2021)**



Source: Authors. Data: statista.de, Bertelsmann Stiftung


$ 22.18 bn PHILIPS
$ 31.59 bn SAP
$ 71.13 bn SIEMENS
$ 84.82 bn SONY
$ 233.72 bn SAMSUNG
$ 112.68 bn ALIBABA
$ 140.30 bn HUAWEI
$ 75.75 bn TENCENT

1.2.1
DISRUPTIVE INNOVATION

In any discussion of tech giants, the issue of disruption or disruptive innovation quickly arises.[15] Pousttchi (2017) defines this as follows: "The term disruption is used if the changes occur suddenly, with a clear break from the past being evident, for instance through the digital transformation of an existing competitor or a competitor newly entering the market."

Disruption is associated with processes of change and renewal that "replace and in some cases even completely displace (…) traditional business models, products and services" (Angerer et al.2019: 10).

However, even when a healthcare system is undergoing digitalization, the changes being implemented cannot be described across the board as disruptive innovations. Norman and Verganti (2014) distinguish between incremental and radical changes. While incremental innovations bring about modifications within a given framework of solutions, radical innovations transform the framework itself, thus leading to new and unique solutions that have the potential to be disruptive (ibid.: 82).

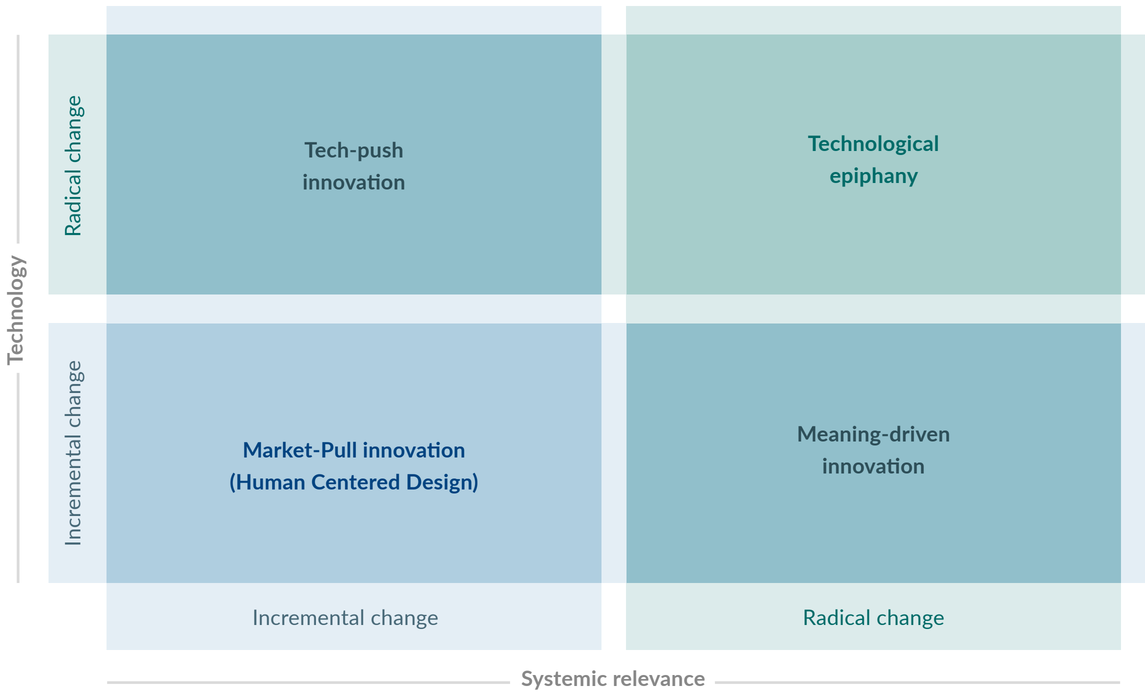


Figure 3: Types of innovation
Source: Authors' own illustration based on Norman and Verganti 2014, p. 89, Bertelsmann Stiftung

15 See inter alia: Meskó et al. (2020), Angerer et al. (2019), Gushurst et al. (2018), Piepenbrink (2019), Levina (2017), Coupette (2014), Kaufman (2018), Hahn and Schreiber (2018).

Figure 3 illustrates how the combinations of these two types of changes, each brought about by new technologies and changes in these technologies' systemic importance, combine to produce four different types of innovation. For example, market-pull innovation is a development that leads to incremental and continuous improvement. Technology-push innovation, by contrast, uses radically new technologies to create incremental changes in the market. Meaning-driven innovation leads to entirely new areas of utility and application through technologies that are experiencing only incremental development over time. Finally, technology epiphanies are disruptive innovations emerging from the application of radically new technologies; these in turn contribute to profound systemic change (Norman and Verganti 2014: 89-90). In German, disruptive innovations are also referred to as "Sprunginnovationen" (Federal Ministry of Education and Research 2021).

In summary, it would not be accurate to describe all digital developments or all of the tech giants' activities in the healthcare sector as disruptive innovations – even though, according to the experts interviewed in this study, many of the technology companies' digital solutions do in fact hold the potential to be disruptive.

1.2.2
THE MOONSHOT MINDSET

Paired with the tech giants' efforts to push radical innovation into all areas of human life is the narrative that Silicon Valley is the "center of global progress" (Schulz 2018: 15). The prevailing sentiment there is also referred to as "moonshot," "moonshot thinking" or the "moonshot mindset." The moonshot concept was popularized by Google founder and former CEO Lawrence "Larry" Page,[16] and refers to the early-1960s vision of manned lunar landings that was promoted by U.S. President John F. Kennedy and others (Schulz 2018). Eric "Astro" Teller heads Alphabet's X Development LLC research division (short version: X; known as Google X until 2016), which calls itself The Moonshot Factory (X – The Moonshot Factory 2020a). Teller offers the following explanation: "Our use of the term 'moonshot' isn't literal; it's more of an emotional blueprint. A moonshot is about looking beyond where you can actually see and envisioning an answer that doesn't seem reasonable – and pursuing it anyway. It's about doing things that sound undoable but if done could redefine humanity" (Teller 2019).

Thus, moonshots entail research into and the development of groundbreaking technologies intended to contribute to radical solutions for problems experienced worldwide (see Figure 4).

The explicit mission of X, the Google-associated think tank and research facility, is to develop highly innovative technologies that might one day make the world a "radically better place" (Teller 2019). Health challenges are among the great current problems in our society that moonshot thinking seeks to solve (Kovarik 2018).

16 The "moonshot mindset" or "moonshot thinking" takes the approach of solving a problem within a particular field that seems unsolvable due to efforts to alter and modify its history, acceptance and growth rate (Roy 2020). This approach long predates Page; its origins stretch back to the so-called waterfall methodologies of the 1950s, which were designed to identify potential grounds for project failure at the point of a project's beginning (Haigh 2018).

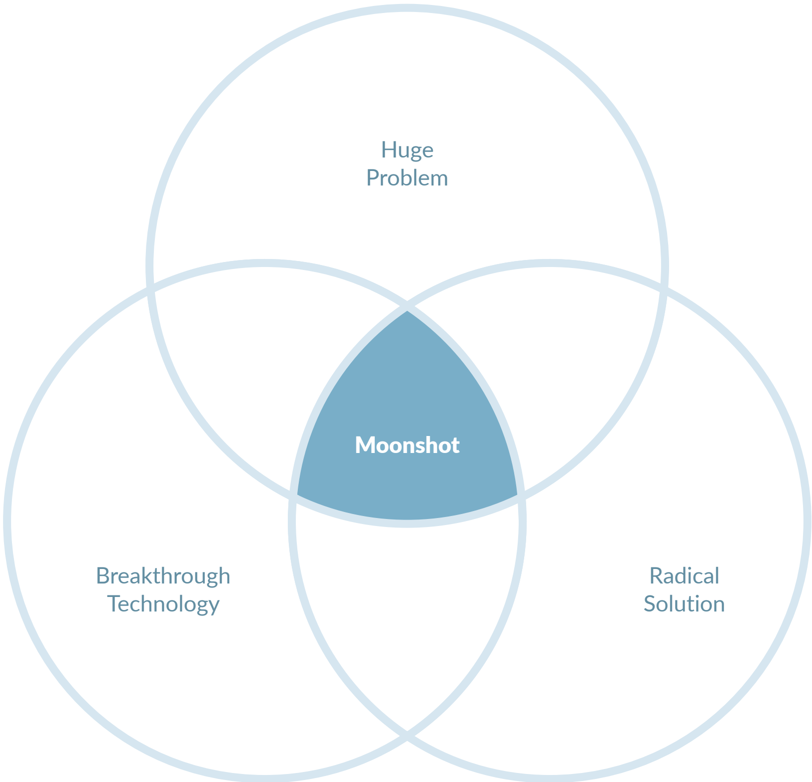


FIGURE 4: **Moonshot**

Source: Authors' own illustration based on X – The Moonshot Factory 2020b, Bertelsmann Stiftung

These ambitious and almost utopian-sounding visions are meant to be realized with the help of the "'10X' philosophy"[17] (Schulz 2018: 103). According to this, every innovation should be 10 times better than the status quo (Schulz 2018: 103; X – The Moonshot Factory 2020b). X's Teller explains: "The secret? It's easier to get people to work on making something 10X better than to get them to help make it 10 % better. Huge problems fire up our hearts as well as our minds. When you're aiming for a 10X gain, you can't just slog through it. You have to find whole new ways of doing things, and lean on bravery and creativity – the kind that, literally and metaphorically, can put a person on the moon" (Teller 2019).

A moonshot mindset can also be used to solve intermediate problems or create intermediate products and services. At worst, this merely results in the collection of valuable data, while in the best case, it solves problems that can give a boost to one or more established companies or startups (Diamandis 2015).

Critical voices, on the other hand, make a distinction between this term and innovations more generally, arguing that while all moonshots can be considered radical innovations, not all innovations are moonshots (Mention et al. 2019: 3-4). For example, moonshots always address significant

17 This philosophy is also one of the 10 components of the moonshot mindset concept. Other components of this corporate philosophy include "Fall in love with the problem" and "Tackle the monkey first" (X – The Moonshot Factory 2020b).

societal problems (Mention et al. 2019), while innovations may relate to more restricted market or societal domains (Taylor 2017). In addition, some critics argue that today's implementation of moonshot projects has nothing in common with what was achieved by the actual moon landing (Haigh 2018). Moonshot approaches can of course lead to failure as well.[18] Nevertheless, to encourage moonshot thinking, some propose that a "failure bonus"[19] be offered for projects that ultimately fail (Huckman et al. 2018).

1.3
RESEARCH INTEREST AND KEY RESEARCH QUESTIONS

This study has several goals: to gain insights into tech giants' current and future activities in the healthcare sector, to reflect on how they are affecting healthcare systems' established structures and operating principles, and to present recommendations for action that are based on an ethically sound analysis.

The specific questions guiding the research include the following:

» What products and services are tech giants already using or developing specifically for the healthcare field?
» Which areas of the healthcare sector and healthcare delivery are particularly attractive from the perspective of tech giants?
» What activities are planned for the digital transformation of healthcare provision and the healthcare sector more generally?
» What ethically relevant opportunities and challenges are associated with the tech giants' activities in the German healthcare sector, particularly with regard to the provision of healthcare?
» How much power will the tech giants be able to develop in the healthcare sector, and what form will this take?
» What measures and structures can be recommended as a means of dealing with the tech giants' healthcare activities – that is, in enabling these activities to be shaped and used according to ethical standards?

To date, no overview of the tech giants' healthcare activities has been provided that is informed by an ethical analysis and which also includes a discussion of the opportunities and challenges involved. Numerous studies have addressed the issue of m-health (mobile health), which encompasses products and services such as wearable electronic devices (wearables) and health and medical apps.[20] In addition, a number of publications have examined the ethical considerations of health in the digital age, dealing with issues such as digital self-determination, privacy, data protection, discrimination, justice and solidarity.

18 See footnotes 12–13.

19 Google's X already uses methods of this kind, providing project teams with a "failure bonus" (Huckman et al. 2018).

20 See inter alia Young et al. (2019), Kim et al. (2019a), Kim et al. (2019b), Kramer et al. (2019), Soliño-Fernandez et al. (2019), Albrecht (2016).

By contrast, this study is the first to present a more comprehensive account of the activities of tech giants in the healthcare sector, as well as an ethical discussion of the associated opportunities and challenges for healthcare systems. Woopen and Mertz (2014) enumerate four functions of ethics as an integral part of a broadly understood assessment of technology. Following their proposal, and given the high ethical relevance of technological developments (legitimation), we focus on technologies deemed to be of particular ethical significance, along with their impact (conceptualization). In doing so, we seek to include a broad range of scholarly and practice-informed perspectives, while evaluating and discussing these technologies using different ethical standards as a basis (evaluation). From this discussion, we subsequently derive recommendations for action (justification of norms).

2 METHODOLOGY

2.1 EXPLORATORY LITERATURE REVIEW

This project began with a cross-disciplinary exploratory review of the literature addressing issues relevant to tech giants in the healthcare sector. Because the subject under review has to date received only sporadic attention by the literature included in research databases, the search was extended to include other publications such as journal articles and so-called gray literature (e.g., corporate press releases and the mission statements of various companies). This research was conducted between May 20, 2020 and September 30, 2020, with additional in-depth research – where needed – being conducted through early January 2022. Further developments after that date could not be taken into account.

Search terms and keywords were identified through an examination of journalism articles in various daily and weekly newspapers, press releases from large technology companies, and independent searches conducted with online search engines (i.e., USB Cologne[21] search portal and Google search). In a next step, our research focused on both multidisciplinary databases (i.e., JSTOR, Google Scholar, Web of Science, and Nexis Uni) and those targeting a specific discipline (i.e., PubMed: medicine/medical ethics; PhilPapers: philosophy; BELIT: bioethics; EconBIZ: economic and social sciences; Business Source Complete: economics). Both German and English search terms were used. As is common with an exploratory research method, no inclusion or exclusion criteria were defined that would have prevented the identification of potentially significant literature in advance. This approach led to the integration of relevant publications from related topics, such as big data, into the analysis. It allowed for the inclusion of gray literature as well.

21 Catalogue of the University and City Library of Cologne and the shared subject and institute libraries (KUG), the catalogues of Cologne public libraries, German unions, periodicals, and selected international catalogues.

The review included publications in German and English only. Given the growth in tech giant activity in healthcare over the past decade, an additional parameter was set to include only publications published since 2010. However, publications prior to 2010 were taken into account if, for example, they were essential to providing a comprehensible estimation of technological developments. Selections were initially made on the basis of a publication's title and abstract; a full-text review determined which items were to be retained or removed from the final list. Publications addressing developments such as m-health and big data without explicitly naming specific companies were also included.

Finally, the bibliographies of each selected publication were analyzed to identify further relevant articles or authors (snowballing). This resulted in a total of 825 eligible publications (including press releases and gray literature).

In the course of the exploratory literature review, four application areas (presented in more detail in chapter →3) were identified in which the activities of tech giants can significantly contribute to the digital transformation of healthcare. The first two areas relate to products and services that are aimed at patients and users on the one hand and at individuals in the healthcare professions on the other. The third area includes system-relevant activities in healthcare provision, and the fourth represents the activities of tech giants in science, research and development. The ethical implications of the tech giants' activities in the four application areas are discussed in chapter →4.

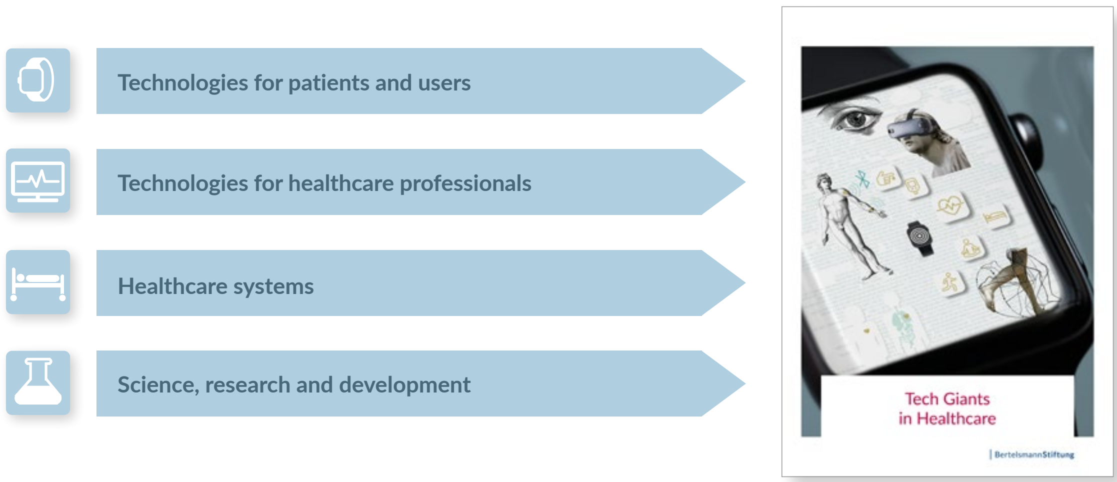


FIGURE 5: **Areas of application relevant to the study**
Source: Authors, Bertelsmann Stiftung

2.2
QUALITATIVE EXPERT INTERVIEWS

In order to gain insights from different areas of practice, the research questions were translated into interview questions. A total of eight guided, non-standardized qualitative interviews were conducted with experts (Kaiser 2014; Bogner et al. 2002) from different fields of research and entrepreneurial activity. Representatives from the industries of pharmaceutics, medical devices, and AI-focused software and technology were interviewed. Representatives from the regulatory and investment sectors were also included, as was an individual representing a trade organization.

The interpretive social science method of paraphrasing (Heinze and Klusemann 1979, 1980; Heinze 1987) informed the analysis of these interviews. In a first step, two researchers independently created paraphrases of the respective interviews, which they then substantiated to each other. This was followed in a second step by a joint critical examination and revision of each paraphrase, which resulted in a formulation of the core statements elicited during each respective interview.

2.3
ETHICAL ANALYSIS

The ethical analysis draws upon those ethical principles and values anchored in legally guaranteed rights and freedoms that are also the focus of ethics bodies acting in an advisory capacity in the field of digitalized healthcare:[22] human dignity, rights to freedom and self-determination, health, privacy, security/safety, justice and solidarity, sustainability and democracy. Forming a two-dimensional matrix, the experts' paraphrased core statements were assigned to the ethical principles and the four application areas mentioned above: (1) technologies for patients and users, (2) technologies for individuals in healthcare professions, (3) healthcare system, (4) science, research and development.

With the literature review and analysis of interviews as a basis, the ethically relevant potentials and challenges posed by the activities of tech giants in healthcare were discussed.

22 See inter alia European Group on Ethics in Science and New Technologies (2021), High-Level Expert Group on AI (2021), German Data Ethics Commission (2019), German Ethics Council (2018).

	ALIBABA	AMAZON	APPLE	GOOGLE / ALPHABET	HUAWEI	IBM	INTEL	META (FACEBOOK)	MICROSOFT	NVIDIA	PHILIPS	SAMSUNG	SAP	SIEMENS	SONY	TENCENT
Technologies for patients and users / healthcare professionals																
Artificial intelligence	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●
Wearables and apps	●	●	●	●	●			●			●	●	●	●		●
Virtual assistant systems and digital avatars	●	●	●	●		●			●						●	●
Augmented reality and virtual reality								●	●			●				
Healthcare system																
Healthcare cloud computing	●	●	●	●	●	●			●			●	●	●		●
Blockchain	●	●			●	●	●		●		●	●	●			●
Medical technology and biotechnology			●	●			●				●			●	●	
Robotics		●				●	●	●	●	●	●	●	●	●	●	
Service provision structures		●	●													●
Insurance in the healthcare sector				●												●
Pharmaceuticals supply	●	●										●				
Mobility and logistics		●		●										●		
Partnerships	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Investments	●	●	●	●	●	●	●	●	●		●	●		●		●
Acquisitions	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●
Science, research and development																
Science, research and development	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

TABLE 1: **Overview of tech giant activities in relevant application areas**

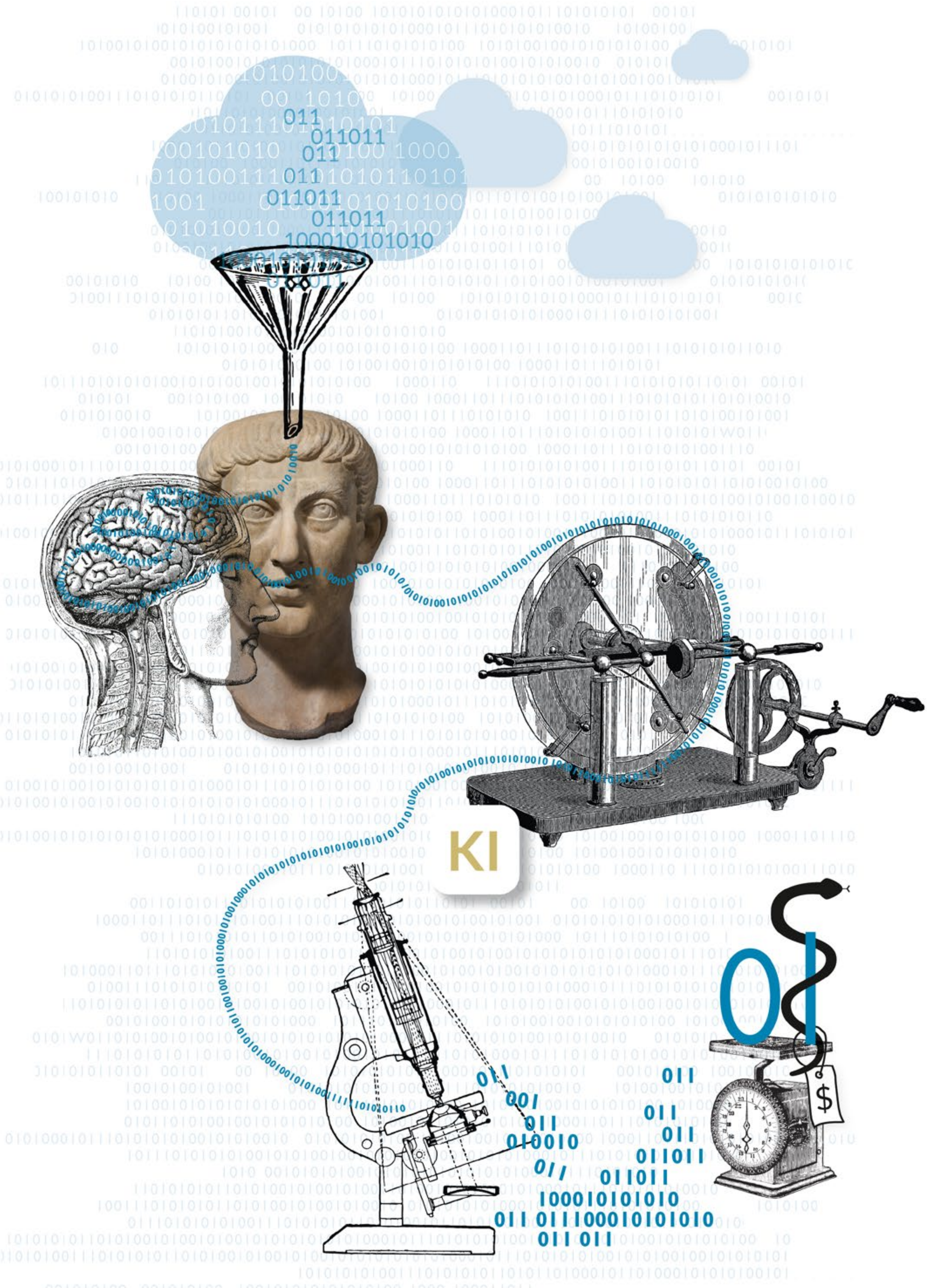
Source: Authors, Bertelsmann Stiftung

3 TECH GIANT ACTIVITIES IN HEALTHCARE

Tech giants are targeting different areas of healthcare provision in a variety of ways. In this study, we examine four different areas of application:

» **Technologies for patients and users**
» **Technologies for healthcare professionals**
» **Healthcare system**
» **Science, research and development**

The boundaries between these areas are not always clear-cut, so cross-references may be included as needed.


KI

3.1 FOUNDATIONS

The collection of machine-readable data and the use of algorithms to process this data form the foundation of digital products and applications offered by the tech giants in healthcare.

3.1.1 MACHINE-READABLE DIGITAL DATA

"Data is an important economic asset in today's world (...). The manifold possibilities for collecting, linking, evaluating and further processing data on a mass scale in digital form open up prospects for new business models and enormous potential for economic value creation" (Piepenbrink 2019).

The collection, preparation and processing of large datasets form "the business foundation of digital transformation and the tech giants" (PwC 2018; Böttinger and Weiß 2019). "Big data"[23] is one of the key terms in present debates concerning the societal changes driven by technology (German Ethics Council 2017b). Hahn and Schreiber (2018: 331), for example, believe that a transformation to highly efficient digital medicine can only take place if the growing volumes of data are efficiently analyzed and interpreted. Today's tech giants have highly developed technological infrastructures that are well suited to this task. Their activities are also partially rooted in the idea "that deciphering biology and understanding disease is ultimately a data problem and can therefore be solved, at least in part, by software experts" (Schulz 2017).

In the health and medical sector, data is often personal health data, such as treatment data relating to individual patients from everyday clinical practice or diagnosis- and treatment-related billing data for health insurance companies. According to the European General Data Protection Regulation (GDPR),[24] certain data fall into a category requiring special protection, mostly according to Art 4 of GDPR. No. 15 of GDPR: "personal data related to the physical or mental health of a natural person, including the provision of healthcare services, which reveal information about his or her health sta-

23 The term "big data" is understood in different ways. As an umbrella term, it can be understood as "a bundle of newly developed methods and technologies" that "enables the collection, storage and analysis of a large and arbitrarily expandable volume of differently structured data" (Research Services of the German Bundestag 2013: 1) or, put differently, as "the processing of large quantities of data, with the aim of discerning patterns and thus gaining novel insights" (German Ethics Council 2017b: 11). Consistent with the English terms, big data is often characterized by the three Vs (Research Services of the German Bundestag 2013; Antes et al. 2017): These include the amount of data (volume) that is "produced in unimaginably large quantities through continuous digitization processes" and is estimated to double every two years (Research Services of the German Bundestag 2013: 1). Since 2020, IBM (2021h) has even assumed the amount of medical data to double every 73 days. Another characteristic is the speed (velocity) by which the data flow takes place permanently and continuously due to "networking and electronic communication" and with which the data must be simultaneously processed (Research Services of the German Bundestag 2013: 1). The third essential characteristic is the heterogeneous nature (variety) of the data, which come from differently structured and highly complex sources. Two additional characteristics are frequently cited as well: veracity (truthfulness and accuracy) and (business) value (material value), the concrete determination of which appears to be difficult (Antes et al. 2017: 38–39).

24 Since its entry into force on May 25, 2018, the GDPR has regulated the collection, processing, use and transfer of personal data throughout the European Union: Regulation (EU) 2016/679 of April 27, 2016, L 119/1 of May 5, 2016, p. 1.

tus." Their processing is generally prohibited and permitted only under specific requirements (see Art. 9 GDPR).

In Germany, legislators recently enacted the Digital Healthcare Act (DVG), which specifies the permissibility of the processing and sharing of health data of persons insured in the Statutory Health Care scheme (SHI) for research purposes in the context of the European requirements (especially Art. 9(2)(j)(4) and 89(1) GDPR) for the German legal sphere.[25] In principle, all non-personal data or personal data collected and processed with the consent of the data subjects are not covered by the prohibition of the GDPR to process them (Art. 9(2)(a) GDPR). This often concerns data generated by patients or users themselves (lifelog data; patient-generated health data) or outside controlled study environments (real-world data).

Health-related big data applications require the broadest possible access to datasets that encompass diverse types and sources of health data (Schulz 2017; Hänisch 2016). This poses questions regarding privacy and data security as well as informational and digital self-determination (Piepenbrink 2019). These and other aspects are discussed in chapter ➔4 as part of the ethical analysis. One must likewise examine whether and to what extent collections of health data should be in the hands of tech giants and what, if any, associated risks society is willing to take for health-related innovations.[26]

One example illustrating this issue is the data sharing arrangement in the partnership between Google DeepMind and the UK National Health Service (UK NHS) which has been controversially debated in the public (Ballantyne and Stewart 2019: 321) (➔3.4.9). Project Nightingale from Ascension and Google provides a further example (Krüger-Brand 2020: 376) (➔3.4.9). The case currently pending before the European Court of Justice (ECJ) against the tech giant Meta (formerly Facebook) in connection with the merging of users' data from different social platforms also shows the explosive nature of how tech giants handle health data (Handelsblatt 2021).

Aspects of informational and digital self-determination are also affected if, for example, AI-based de- and recontextualizations of data obscure the degree of their sensitivity, or if initially anonymous data, for example in connection with a multitude of other data of different natures, allow the re-identification of a specific person. In addition, the relinking of data can be used to create profiles on behavioral patterns from the combination of consumption and health data on healthy or unhealthy eating habits, for example, and to form risk groups (German Ethics Council 2017b; Meier 2019) (➔4.3.1 and ➔5).

Experts interviewed for this study are convinced that tech giants will intensify their core business of data acquisition in the future and develop entire ecosystems of data-generating and data-processing products and services. Many technology companies maintain their own digital infra-

25 See Fn. 3.

26 According to Böttinger and Weiß (2019: 7–10), the actual business model of the tech giants is based on collecting as much behavioral data as possible by means of the health-related products and services offered, and on creating personal profiles of users aimed not only at influencing their decisions in the future, but also at making them. For further elaboration, see Piepenbrink (2019), Zuboff (2019), and the German Data Ethics Commission (2019). For further reference, see also Couldry and Mejias (2020).

structures (cloud computing) to facilitate the merging and processing of these comprehensive data sets (→3.4.1).

3.1.2 ALGORITHMIC SYSTEMS AND ARTIFICIAL INTELLIGENCE

Processing large quantities of data and generating insights requires algorithmic systems, most of which fall under the category of artificial intelligence, including machine learning and deep learning (Data Ethics Commission 2019: 57–62).

Machine learning (ML) is "a rapidly growing subfield of computer science that deals with models and methods of data analysis and is interwoven into a wide range of application areas. (…) In most cases, a specific statistical model is 'trained' using data. In the typical case of automatic classification, systems use specific training data sets to 'learn' computational rules that classify or categorize data in a particular way" (German Ethics Council 2017b: 72–73).

In a further development, deep learning (DL) "replicates processes along hierarchically organized layers, similar to the mode in which neural networks operate in the human brain. Each layer uses the results of the previous layer and processes them further to produce new results. Given the increasing volume of data and increased computing power, the networks in use today contain more interconnecting intermediate layers than ever before. The key difference to traditional methods is that in Deep Learning, the process of extracting characteristics has also been automated to a large extent and models can often be trained directly with raw data. This can reduce dependence on complex pre-processing steps, which can also include developer biases and intuitions" (German Ethics Council 2017b: 74).

In current usage, different forms of self-learning algorithmic systems are referred to using the term "artificial intelligence (AI)" (Data Ethics Commission 2019: 59; German Ethics Council 2017b: 75). A distinction is made between „artificial narrow intelligence" (ANI), "artificial general intelligence" (AGI) and „super intelligence". ANI can solve "well-specified tasks;" AGI is intended to handle "a wide range of tasks, possibly without human intervention" (Data Ethics Commission 2019: 59), which is not yet possible. Meanwhile, "super intelligence" describes a hypothetical system that not only mimics, but also exceeds human intelligence and develops self-awareness (Escott 2017).

AI is widely regarded as the "most pressing, exciting, promising – but also dangerous – technology issue in the world since man learned to split the atom" (Schulz 2018: 64). The medical field is one of the most prominent and rapidly growing fields of application and investment in artificial intelligence (Kaufman 2018; German Ethics Council 2017b).[27] Numerous hopes and visions for the future are formulated (see, among others, Topol 2019a; Hütten 2019; Ferryman and Winn 2018); for example, that AI-based applications will lead to substantial advances in the clinical areas of

27 Following its acquisition of Nuance Communications Inc., a company specialized in AI, in 2021, Microsoft CEO Satya Nadella announced: "AI is technology's most important priority, and healthcare is its most urgent application" (tagesschau.de 2021b).

Tech giants and artificial intelligence
(Selected URLs for current projects and recent publications)

ALIBABA
→ https://damo.alibaba.com/pubs/

AMAZON
→ https://www.amazon.science/publications

APPLE
→ https://machinelearning.apple.com/research?page=1&tag=Health

GOOGLE
→ https://research.google/research-areas/health-bioscience/
→ https://research.google/teams/brain/
→ https://ai.google/research/
→ https://deepmind.com/research

HUAWEI
→ https://www.huawei.com/en/technology-insights/industry-insights/technology/ai
→ https://e.huawei.com/en/publications/global/ict_insights

IBM
→ https://research.ibm.com/artificial-intelligence

INTEL
→ https://www.intel.com/content/www/us/en/research/publications.html

META (formerly Facebook)
→ https://research.fb.com/publications/

MICROSOFT
→ https://www.microsoft.com/en-us/research/blog/
→ https://blogs.microsoft.com/ai/

NVIDIA
→ https://www.nvidia.com/en-us/research/ai-playground/
→ https://research.nvidia.com/publications

PHILIPS
→ https://www.philips.com/a-w/research/research-programs/ai-research-at-philips-research-north-america.html
→ https://www.philips.com/a-w/research/downloads-and-publications.html

SAMSUNG
→ https://research.samsung.com/artificial-intelligence
→ https://research.samsung.com/research-papers/paper/search

SAP
→ https://www.sap.com/about/company/innovation/open-access-research-publications.html?sort=title_asc

SIEMENS
→ https://www.siemens-healthineers.com/medical-imaging/molecular-imaging/mi-clinical-corner/scientific-and-clinical-publications
→ https://www.siemens-healthineers.com/en-us/magnetic-resonance-imaging/published-studies
→ https://www.magnetomworld.siemens-healthineers.com/publications/magnetom-flash
→ https://www.siemens-healthineers.com/Covid-19/Covid-19-resources

SONY
→ https://www.sony.com/en/SonyInfo/sony_ai/

TENCENT
→ https://ai.tencent.com/ailab/en/paper/?page=1

prevention,[28] diagnostics[29] and treatment[30] as well as in science and education (Krüger-Brand 2020; Choueiri et al. 2019; Schulz 2018; PwC 2018, 2017).

However, AI-based technologies can pose considerable risks of discrimination and stigmatization; their mode of operation is often even beyond the understanding of the developers themselves ("blackbox medicine"), and they can also be used for controversial purposes, such as surveillance.[31] The ethical aspects are discussed in chapter ➔4.

Tech giants are investing heavily in the development of AI-based systems and applications. This also includes significant competition in the recruitment of "AI talents"[32] (Lewis-Kraus 2016). The following are examples of the activities of the tech giants in the realm of AI.

GOOGLE has "essentially been a machine learning project" since the company's founding in 1998 (Schulz 2018: 77). Google and Alphabet CEO Sundar Pichai has repeatedly emphasized that Google is transforming itself into an artificial intelligence company (Pichai 2017a, 2017b). That goal is reflected in the health sector, for example, in numerous research projects, as well as in high levels of investment (Schulz 2018: 78).

The Google Health division,[33] founded in 2006, attempted to collect electronic health data in the form of an electronic health record (EHR) and derive recommendations in an initial project that was discontinued after a few years (Meskó et al. 2020: 8–9). Since then, Google Health has focused on numerous research projects related to applications for everyday clinical practice and works with various medical care providers as well as governmental and academic partners (Google Health n. d. d, b, c) (➔3.5). One focus at Google Health is computer vision, which is used in the fields of medical imaging and diagnostic applications (Meskó et al. 2020: 14) (➔3.5).

In 2011, the company launched its Google Brain research unit as a project of the Alphabet subsidiary X. The team at Google Brain is engaged in the research and development of deep learning algorithms and AI applications, including in the area of healthcare provision. Researchers at Google Brain have developed, for example, TensorFlow, the world's leading open-source machine learning platform (Lewis-Kraus 2016). Google Brain has been a division of Google AI ever since the unit, dedicated

GOOGLE / ALPHABET

Google Health

Google Brain

DeepMind

DeepMind Health

28 Wearables and apps are considered promising with regard to AI-assisted health promotion and prevention because they can collect and monitor vital data and, in case of deviations from the norm, provide a warning to the affected patient and also to healthcare professionals (➔3.2 and ➔3.3) (Hahn and Schreiber 2018).

29 For example, AI-based ultrasound and X-ray technologies will be able to independently identify diseases as diagnostic imaging procedures. These technologies also hold promise in the diagnosis of rare genetic conditions by, for example, using facial recognition, because the machines can process a large amount of information about rare diseases from databases, whereas physicians have often only seen a few cases, which can make a correct diagnosis difficult (Winkler et al. 2020; Gurovich et al. 2019; Schulz 2018).

30 In the area of treatment, AI-based systems can provide support in, for example, intraoperative procedures by improving endoscopic navigation or 3D visualization during computer-assisted surgery, in addition to other applications (Central Ethics Commission of the German Medical Association 2021).

31 See, among others: Central Ethics Commission of the German Medical Association (2021), WHO (2021a), Mozur, et al. (2020), Johnson (2020), Data Ethics Commission (2019), Robbins (2019), Floridi, et al. (2018), Kaste (2018), Pasquale (2015).

32 Meta (formerly Facebook) promises up to seven-figure starting salaries to talent in the field of AI, for example (Kaufman 2018). Apple has responded by paying developers up to $180,000 in stock options in order to get them to stay with the company (Heming 2021).

33 According to statements by Dr. David Feinberg, head of Google Health, Google is already a health company, with health aspirations written into its DNA since the company's inception (Google Health 2019).

exclusively to AI research, was founded (Meskó et al. 2020: 8).

In 2014, Google acquired the London-based startup DeepMind, which is focused on artificial general intelligence (AGI). For the development of applications in the healthcare sector, the company founded its DeepMind Health offshoot, which developed the medical smartphone app Streams (➔3.3). DeepMind Health became involved in numerous partnerships and was also the subject of criticism for some of its projects (Meskó et al. 2020: 10–15) (➔3.4.9).
In 2019, the team at DeepMind Health and the app Streams were incorporated into the Google Health division (King 2019), which has also been the subject of public controversy (➔3.4.9). DeepMind achieved a breakthrough in November 2020 as part of AlphaFold (CASP), when it succeeded for the first time in determining the 3D shape of proteins based on their amino acid sequences using deep learning (Callaway 2020).

APPLE

Apple Machine Learning Research

APPLE has dedicated its Apple Machine Learning Research division to AI research projects.
In July 2017, Apple launched the Apple Machine Learning Journal to provide an overview of the company's current projects in health-related AI research and other areas (Insel 2017; Apple Machine Learning Research 2021a, 2021b).

Apple's AI / ML Residency Program provides participants in the one-year program with ML and AI training as well as courses on developing AI-based solutions and products (Apple Machine Learning Research 2022).

META (formerly Facebook)

AI-based applications

fastMRI

META (formerly Facebook) uses AI to reduce the sharing of misinformation or false information on its platforms about topics such as COVID-19 (Facebook AI 2020b; Jakob 2019). In the course of this process, Meta says it worked with more than 60 independent organizations that fact-check and label the content in question (Facebook AI 2020b).[34]

Meta also uses AI in some countries to identify people at risk of suicide on the social network facebook. The technology evaluates not only what the person is writing, but also comments that are posted in response. If a person is assessed as being at risk, staff members then decide whether to inform the police (Kaste 2018) (➔4.3.1).

Facebook AI Research (FAIR) and New York University (NYU) Langone Health are collaborating on fastMRI, an AI-based medical imaging research project (fastMRI 2020) (➔3.5).

34 In late 2021, Frances Haugen, a former product manager at Facebook's unit dealing with misinformation, lodged serious allegations against Facebook (now Meta). Speaking before the U.S. Subcommittee on Consumer Protection, Product Safety and Data Security, she accused the tech giant of putting corporate profits ahead of the well-being and safety of users and basic societal principals such as democracy by, among other things, knowingly using algorithms "that amplify divisive and harmful content" (tagesschau.de 2021f, 2021e).

AMAZON is pursuing numerous activities in the field of AI, such as the development of AI-assisted recognition and translation programs. Amazon Rekognition Video, for example, includes a deep learning video analytics function that can detect, track and extract objects, faces and content from video (Walker 2017). This could ultimately be relevant for medical imaging in the healthcare sector.

With Amazon Transcribe Medical, an automated speech recognition (ASR) service, speech-to-text capabilities can be used. The service is used in a wide variety of medical fields. According to Amazon, the service can be used to precisely transcribe conversations between doctors and patients, for example (AWS 2021b).

Amazon Translate is a neural machine translation service that the company claims can produce highly accurate and authentic translations (AWS 2021c).

Amazon Comprehend Medical is an ML-based natural language processing (NLP) service that extracts health data and information from medical texts. The data can be used for health analyses, in the execution of clinical studies, for pharmacovigilance and to provide an overview. They can also be linked to medical ontologies such as ICD10-CM[35] or RxNorm.[36] The aim of Amazon Comprehend Medical is to make all medical and health information easily accessible and retrievable (AWS 2021a).

Amazon's virtual assistant Alexa is also AI-based and is already being used intensively in the healthcare sector (➔3.2).

AMAZON

Amazon Rekognition Video

Amazon Transcribe Medical

Amazon Translate

Amazon Comprehend Medical

Amazon Alexa

MICROSOFT is running numerous AI projects such as the Microsoft Healthcare NExT initiative, which aims to transform healthcare by leveraging existing AI and the Azure Cloud (Microsoft Feb. 16, 2017) (➔3.4.9).

Microsoft's AI for Good initiative is the umbrella for various programs such as AI for Earth, AI for Humanitarian Action and also AI for Health (➔3.4.9 and ➔3.5), which are designed to address major crises and pursue UN sustainability goals in cooperation with non-governmental organizations (NGOs) and other humanitarian organizations. Microsoft along with, for example, IBM is also part of the UN International Telecommunication Union's (ITU) platform AI for Good, which is dedicated to achieving these sustainability goals using AI and, to that end, brings innovators together with "problem owners" (Microsoft 2022; ITU 2021; Smith 2018).

Microsoft is also collaborating with Nuance Communications, Inc. on Project EmpowerMD, which processes conversations between physicians and patients, integrates the content into electronic health records (EHR) and automatically provides a medical summary. The system uses a large number of algorithms designed to recognize complex natural language and process its content. The system is designed to learn from all interactions and thus to help ensure the best medical outcome (Microsoft Research 2019; Microsoft News Center Oct. 17, 2019) (➔3.4.9).[37]

Microsoft's Project Hanover, launched in 2016, aims to advance the technological foundations of machine reading for precision medicine. It combines deep learning and probabilistic logic. The project is currently focused on molecular tumor research as well as on generating evidence from real-world

MICROSOFT

Microsoft Healthcare NExT

Microsofts AI for Good Initiative

Project EmpowerMD

Project Hanover

Novartis AI Innovation Lab

Microsoft (Azure) Health Bot Service

35 International Classification of Diseases, Tenth Revision, Clinical Modification.

36 RxNorm links clinical drug use names to drug vocabularies used in pharmacy management and drug interaction software to ensure standardization of drug names across systems (National Library of Medicine (NLM) 2021).

37 Project EmpowerMD works with the system Dragon Ambient eXperience (DAX), which records and processes doctor-patient conversations during everyday visits (Microsoft 2021a).

healthcare provision in conjunction with clinical trials (Microsoft Research 2016).

Microsoft is collaborating with SilverCloud Health, to support its digital health platform with AI-based applications (Meskó et al. 2020: 6) (➔3.4.9).

Microsoft is working with the pharmaceuticals company Novartis as part of the Novartis AI Innovation Lab (Evans 2020) (➔3.4.9).

Microsoft's (Azure) Health Bot service is an AI-based platform designed to support the integration on virtual assistants and chatbots (Microsoft 2021c; Microsoft Research 2021a) (➔3.3).

IBM

IBM Watson Health

AI Horizons Network

IBM's Watson Health seeks to create solutions for the healthcare system using AI, data analytics and blockchain technologies. Data and knowledge are harnessed to support well-founded decisions in the healthcare context, to increase efficiency in companies and in the healthcare sector, and to improve clinical trials (IBM 2021h) (➔3.2 and ➔3.4.9).

The AI Horizons Network is a global network of researchers initiated by IBM to further develop the use of AI, natural language processing (NLP) and related technologies (IBM Apr. 28, 2020) (➔3.4.1 and ➔3.5).

INTEL

Deep Learning Analytics Platform

INTEL and the Center for Digital Health Innovation (CDHI) at the University of California, San Francisco (UCSF) are collaborating to jointly deploy and validate a deep learning analytics platform. It is designed to improve medical care by helping clinicians make better treatment decisions, predict patient outcomes and respond more nimbly in acute situations (Meskó et al. 2020: 56; UCSF Jan. 18, 2017).

In partnership with the Center for Biomedical Image Computing and Analytics (CBICA) at the University of Pennsylvania Medical School and 29 other healthcare institutions, Intel is using federated learning[38] to develop AI to help detect brain tumors (Council 2020; Proffitt 2020).

NVIDIA

NVIDIA Clara

NVIDIA Clara Train SDK

NVIDIA Clara is a platform and application model that aims to drive healthcare innovation and precision medicine through the use of AI and intelligent computing. The areas of genomics, observation of the health status of patients, medical imaging and drug development are its focus (NVIDIA 2021d; The Medical Futurist 2018) (➔3.3, ➔3.4.3 and ➔3.5).

NVIDIA Clara Train SDK is an application framework designed to support the sharing of data and knowledge between hospitals and medical facilities through federated learning in ways that allow algorithms to be trained without jeopardizing the privacy of patients. The collaborative learning model is intended to allow different institutions to work together safely and thus contribute to a global model (Wen et al. 2019) (➔3.4.3).

38 Federated learning allows an AI model to be trained using local data samples. To improve model accuracy, local models are shared in the network and fed into a global model that is shared with all users (Fraunhofer Institut 2022).

SIEMENS, by its own account, holds several hundred patents relating to machine learning (ML) and has developed numerous AI-based healthcare-related applications that are designed not only to optimize healthcare workflows but also to automate complex diagnostic procedures (Siemens Healthineers 2020a) (➔3.3).

SIEMENS
AI-based applications

SAP offers cloud and AI-based platforms that are designed to schedule appointments and operations, simplify documentation, equip patients with specialized apps and programs, provide analytics and insights for predictive purposes, improve medical procedures through accurate real-time data, secure medical documents and patient information and store all data-based information (Approyo 2019).

SAP
AI-based platforms

HUAWEI provides various AI-based services with its Huawei Cloud for, among other things, combating COVID-19 (Huawei Cloud 2021b) (➔3.2, ➔3.4.1 and ➔3.4.9).

HUAWEI
Huawei Cloud

ALIBABA Health is collaborating with three hospitals in China on a first-of-its-kind medical AI lab. The lab will be used to test how AI can be used to support diagnostic as well as clinical decision-making processes. Other areas in which AI is slated for use include intelligent medicine (including general data use, biotechnology, environmental information and analysis to steer medical decisions), as well as online medical services and personal health management (Business Insider Intelligence 2018).

ALIBABA
Alibaba Health
KI-Labor

TENCENT operates three major AI labs to support AI-based medical research and other applications: Tencent Medical AI Lab, Tencent YouTu Lab and Tencent AI Lab (Tencent 2019) (➔3.5).

TENCENT
Tencent Medical AI Lab
Tencent YouTu Lab
Tencent AI Lab

3.1.3 SUMMARY

Tech giants have massive capabilities for collecting and processing data, even if it comes from disparate sources. A wide variety of AI systems are being developed and deployed to analyze and process the data. Developments in healthcare range from general storage and analysis platforms to disease-specific applications. The aim is to further develop precision medicine by collecting the relevant individual data as comprehensively as possible, but also to clarify medical-biological relationships such as fundamental metabolic processes, and to optimize care processes.

With the help of AI systems in imaging, speech recognition, virtual assistance systems or the development of a digital twin, both individual treatment and the care process are to be optimized. In 2019, the market for AI in healthcare was $ 3.48 billion, and it is expected to reach $ 40.12 billion by 2026, growing at an annual rate of 41.8 % during the forecast period (Medgadget 2020). Other estimates suggest that global spending on AI in the healthcare sector will grow at an annual rate of 46.2 % during the projected period to $ 67.4 billion by 2027, which would be nearly 10 times the $ 6.9 billion spent in 2021 (MarketsandMarkets Research 2021).

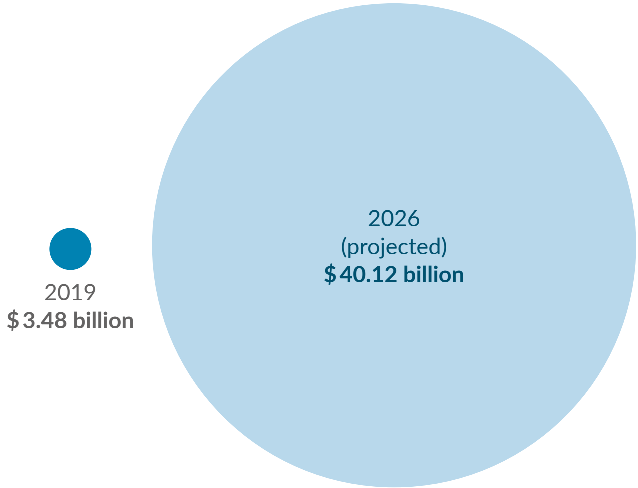
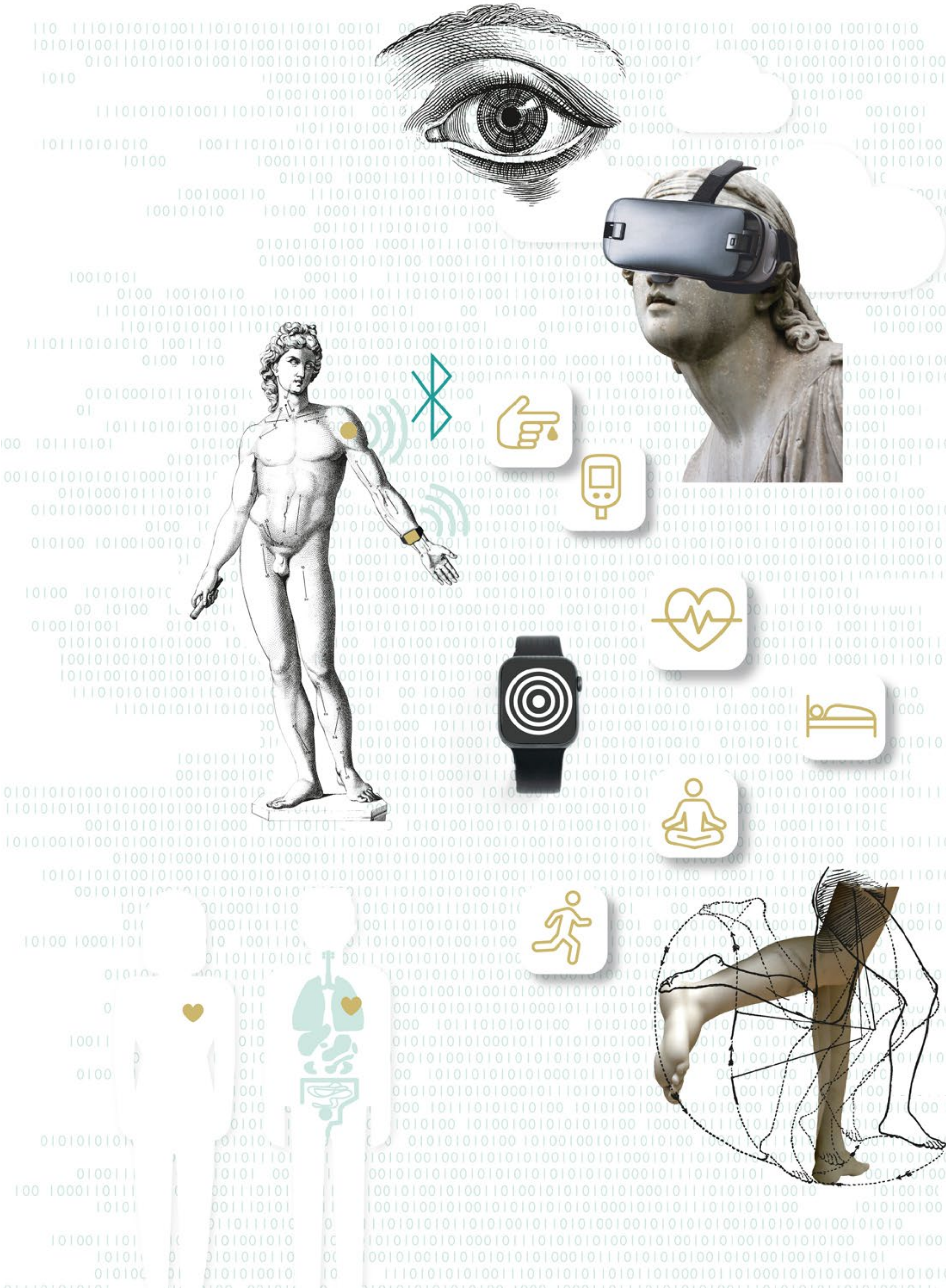


FIGURE 6: **Market for AI in healthcare**
Source: Authors. Data: Medgadget 2020, Bertelsmann Stiftung



3.2 TECHNOLOGIES FOR PATIENTS AND USERS

This chapter presents digital products and services produced by the tech giants that are offered to and used directly by patients. It is also concerned with users who utilize health-related technologies outside the context of professional healthcare for the purposes of improving or maintaining their own health and preventing disease, and consequently cannot (yet) be referred to as "patients."

3.2.1 WEARABLES AND APPS

Wearables and apps play a prominent role in the mobile health field (m-health). Development in this area is moving very rapidly, and the market is very dynamic.[39] To date, m-health products and services have focused primarily on the lifestyle and prevention markets, as well as on the management of chronic conditions such as diabetes, obesity, depression and cardiovascular diseases (Bienhaus 2016). Many wearable devices can also be connected with one another or be linked to social platforms and networks, thereby allowing, for example, users to compare their athletic performances with others.

Wearables can be described as "electronic devices worn on the wrist, head, ears, clothing or skin that can be directly connected to the web via a wireless (e. g., Bluetooth) link to a smartphone or tablet. Such devices have smart sensors that can measure and process a broad range of physical and physiological variables. When they are implanted under the skin, they are called 'insideables.' Depending on the application and the way the device as worn, a distinction can be made between smartwatches, smart glasses, headsets, smart earphones, technology tattoos, fitness trackers, running watches, smart clothing, smart jewelry, etc." (Mischak 2017: 278–279).

The associated software components, usually referred to as apps, can also be distinguished based on their context of use. For example, a distinction is made between health apps, which are used to manage, maintain and improve one's own health; medical apps, which deal with the diagnosis, therapeutic treatment and monitoring of (primarily chronic) conditions; and pure lifestyle apps, which address issues such as fitness and wellness (Schüz and Urban 2020: 192). From a legal perspective, the question of whether a health-related app is deemed a medical device is also relevant;

39 Many of the tech giants' m-health innovations have already been replaced by newer innovations, or have been driven out of the market by other developments. These include the Samsung Simband, a smartwatch described by Samsung as an "investigational device" that was intended to act as a "window into the wearer" (Sullivan 2017; Samsung Simband 2018). According to media reports, the initial presentation of the Simband prototype in 2014 has not been followed by any further releases of this product. In 2014, the Simband would have been in direct competition with the not-yet-released Apple Watch. However, by 2017, Simband had lost market relevance, and it can be assumed that Samsung abandoned the project (Sullivan 2017). For its part, Microsoft took its Microsoft Band (a second-generation smartwatch with an associated app) off the market in 2019 (Microsoft Support 2019).

in the EU, this makes it subject to the special rules contained in the regulation on medical devices,[40] which cover issues such as market entry, evaluation, testing and monitoring. This is primarily based on whether the items or apps in question are "intended to be used, alone or in combination, for human beings for (…) a specific medical purpose ."[41] Additionally, in Germany for example, there is the question of whether the costs for a health-related app are eligible for reimbursement through the statutory health insurance (GKV) system. This is dependent on whether it is classified and recognized as a Digital Health Application (DiGA) under the requirements and regulations contained in the Digital Healthcare Act (DVG).[42]

APPLE has already positioned itself in the healthcare market with a complex ecosystem of wearables and apps that are designed to be user-friendly and easily connected to other devices or the internet. The overall size of the global m-health market, within which Apple is a key player, is expected to reach a value of $ 311.98 billion by 2027 (Smith 2020).

Using Apple's applications often requires access to an iPhone. iPhones accounted for a 15.2 % share of all new smartphone sales globally in the third quarter of 2021 (Tenzer 2021); other estimates indicated that this share was as high as 23.4 % in the first quarter of 2021 (tagesschau.de 2021a). Apple led the global smartwatch-sales market in the first quarter of 2021, with a 33.5 % market share, followed by Huawei with a 8.4 % share (Koetsier 2021). Other sources estimated that Apple's market share was as high as 52.2 % (Macdailynews 2021).

The company launched its Apple Health app in 2014. Distributed as preinstalled software on newer iPhone versions, this can aggregate health-related data from the iPhone and the Apple Watch, as well as from other providers (Meskó et al. 2020: 19).[43] The Apple Health app serves as a platform that allows patients and users to combine and analyze their own medical data along with other self-generated health and lifestyle data (Krüger-Brand 2020: 378).[44]

The Apple Watch is another wearable device. Now available in its seventh generation, this smart wristwatch was first introduced to the lifestyle market in 2014 as a health and fitness tracker. The company has integrated new functions into the Apple Watch with each new generation; over time, the goal is to transform it into a full-fledged medical device (Meskó et al. 2020: 22). While it has long been able to measure data associated with sports activities, for example, it has since the fourth generation been able to record an electrocardiogram (ECG) via the AliveCor KardiaBand, and thus display the user's heart rhythm and heart rate (Apple 2020; Krüger-Brand 2020: 378) (→3.4.3).

By using the Apple Research app, Apple smartphone and smartwatch users can participate in Apple studies, and even organize them (Apple 2021c) (→3.5).

APPLE

Apple Health App

Apple Watch

Apple Research App

Covid-19-App

Interfaces for Covid-19-Contact-Tracing-Apps

40 Parliament and Council regulation (EU) 2017/745 of 5 April 2017 on Medical Devices, L 117/1 of May 5, 2017 (Medical Devices Regulation, MDR).

41 These are, in particular, the diagnosis, prevention, monitoring, prediction, prognosis, treatment or alleviation of disease; the diagnosis, monitoring, treatment or alleviation of injury or disability, or measures intended to compensate for such a condition; or the examination, replacement or modification of the anatomy, or of a physiological or pathological process or condition, etc., see Art. 2 MDR.

42 See footnote 3.

43 Apple acquired Gliimpse, a startup that specialized in aggregating and organizing health data, in 2016. In 2018, Apple added the ability to integrate proprietary medical data from medical institutions into the Apple Health app (Meskó et al. 2020: 19–20).

44 The Apple Health app complies with the Fast Healthcare Interoperability Resources (FHIR) standard published by the Health Level Seven International (HL7) organization, which has established itself as a global interoperability standard "for data exchange between healthcare software systems" (Krüger-Brand 2020: 378).

Apple also provides a COVID-19 app that informs individuals who have received coronavirus tests of their test results (Meskó et al. 2020: 22-23).

In April 2020, Apple introduced its own application programming interface (API) that was, co-developed with Google, for COVID-19 contact-tracing apps. This subsequently served as a de facto standard for most European mobile-phone-based contact-tracing apps (Fanta 2020; Sharon 2020), such as the German Corona-Warn-App (Federal Ministry of Health 2021a) (➔this chapter, SAP). In addition, as a part of their collaboration, the two tech giants created technology for Android- and iOS-based smartphones that allows users to anonymously report contact with a person suffering from COVID-19, without any involvement by health authorities, using the so-called Exposure Notifications Express system (Laaff 2020; Federal Ministry of Health 2021a).

Apple has thus pursued a wide variety of activities in the area of technologies for patients and users. It is clear today that smartphones themselves – and thus also Apple's own iPhone, particularly used in conjunction with the company's own apps (e.g., the Apple Health app), third-party apps and compatible connectable wearables (e.g., Apple Watch) – are increasingly gaining significance as medical devices in their own right, both with regard to healthcare provision and medical research (Topol 2015).

GOOGLE / ALPHABET

Google Fit-App

Fitbit & Fitbit App

Google Health & Google Health Studies App

Interfaces for Covid-19-Contact-Tracing-Apps mit Apple

GOOGLE Wear OS is a Google-built operating system derived from Android and developed further for mobile devices. It is compatible with numerous smartwatches, and allows these to be synchronized with smartphones. Among other things, the smartwatches can be used to monitor health and fitness goals, with the resulting information being used to facilitate these goals' achievement (Google Play Store 2021e). The Google Fit app can be used on smartwatches and smartphones, with all data synced across the devices. The app was developed in partnership with the World Health Organization (WHO) and the American Heart Association (AHA) (Google Play Store 2021a).

Fitbit, which was acquired by Google in 2021, produces smartwatches and other tracking devices that can measure a user's pulse, stress level, sleeping patterns and blood oxygen levels, and can derive a cardiac waveform (ECG) from the information gathered. The Fitbit app can be used to analyze and synchronize the data collected (Maehner 2020). Fitbit ranked fifth in the global smartwatch market, with a 4.2 % share, as of the first quarter of 2021 (Koetsier 2021).

The Google Health Studies app is intended to encourage patients and users to contribute to medical research (Google Play Store 2021b) (➔3.5).

In addition, Google's search engine (Google Search) provides the ability to search for information on common medical conditions, symptoms and treatment options online – although there are certainly challenges with regard to assessing the quality of health information on the internet.[45]

Google Health, according to the company's own statements, is intended to help improve women's physical and mental health, using an online self-assessment questionnaire on the issue of postnatal depression (Google Health 2020).

For a discussion of Google's collaboration with Apple on the API for COVID-19 contact-tracing apps, see the discussion of Apple in this chapter.

45 This problem is not discussed in this study. For further information on the topic and related research, see, for example, projects such as OriGes (https://ceres.uni-koeln.de/en/research/projects/origes-ii).

META (formerly Facebook) offers a tool called Preventive Health, an opt-in feature that can be added within the social network's Facebook app that provides U.S. users with recommendations for health checkups. The recommendations are made based on guidelines issued by the U.S. American Cancer Society (ACS), the American College of Cardiology (ACC), the American Heart Association (AHA), and the Centers for Disease Control and Prevention (CDC). The tool currently provides preventive health screening recommendations for cardiovascular diseases, cancers and the flu (Facebook 2020).

META
(formerly Facebook)

Preventive Health

PHILIPS' SmartSleep Deep Sleep Headband is a headband intended to analyze and improve sleep patterns. Designed in collaboration with physicians and researchers, its target market is individuals who regularly sleep less than six hours per night (Philips 2021i, 2021f). The SmartSleep Snoring Relief Band uses vibrations to guide users into a side sleeping position, with the goal of preventing snoring. It uses a position-measuring device to determine whether users are lying on their backs or not (Philips 2021j).

The Philips HealthSuite is a cloud-based platform for connecting different healthcare devices. Clinical data and other data from any Philips device can be aggregated and analyzed within the Health-Suite. Medical and nursing staffers at healthcare institutions can access patient health data, as can the patients and users themselves. The Health-Suite consists of the eCareCoordinator app, which is designed for physicians (➔3.3), and the parallel eCareCompanion, which was developed to help patients become more actively involved in their own treatments, and to improve their personal health management. Patients can perform functions such as entering vital signs and blood-pressure values, or can call up an overview of past measurements. The personal data is additionally supplemented by subjective data from digital health questionnaires. eCareCompanion is intended to be used with additional tools including a scale, a wireless blood glucose meter, a finger pulse oximeter and a blood pressure monitor. These devices report the data measured to the eCareCompanion, which then processes it (Philips 2021c, 2021d). The company also offers the mobile HealthSuite Health app, which is intended to support users who want to change their habits by allowing them to measure their own vital signs and providing them with health advice (Philips 2021e).

The Philips Heart Health Program, an app-based health program, is intended to help reduce risk factors for cardiovascular diseases by encouraging users to make lifestyle changes. It provides users with a personalized health plan that helps them increase their physical activity and improve their diet and sleep patterns, among other features (Philips 2017).

PHILIPS

Philips SmartSleep Deep Sleep Headband

Philips SmartSleep Snoring Relief Band

Philips HealthSuite & HealthSuite App

Philips Heart Health Program

AMAZON's Care app, is currently reserved for employees of Amazon. The app is intended to facilitate access to high-quality telemedicine-based healthcare services. To this end, a team of doctors and nurses is available at all times to provide services through the app. A text function can be used to obtain advice on any health topic. Users can also obtain advice, diagnoses, treatment or referrals via video chat (Amazon Care 2021; Amazon March 17, 2021).

The Amazon Halo Band is a fitness wearable that was launched in 2020. Instead of a display, it has two integrated microphones and an optical sensor used to measure the user's heart rate. In addition to the heart rate, Amazon Halo can also monitor

AMAZON

Amazon Care App

Amazon Halo Band & Halo App

and analyze a user's sleep patterns (Mühlroth 2020). With the Tone feature, the device's microphones can be used to analyze the user's voice.[46] In addition, the device can be used to generate a 3D body-fat model.[47] Amazon Halo works with the Halo app, which runs on both the iOS and Android operating systems. Among its other features, the Halo app offers workouts designed with the goal of helping users develop health-promoting habits. Amazon Halo Labs partners include John Hancock,[48] 8fit, the American Heart Association (AHA), Headspace and WW[49] (formerly Weight Watchers) (Amazon August 27, 2020). Amazon faces a serious challenge with its Amazon Halo line, as the market is already crowded with different wearables (Erum 2020).

SAP

SAP Health Engagement

Corona-Warn-App

SAP Health Engagement, a cloud-based application, is built on SAP's HANA cloud platform. It aims to improve interactions and the exchange of information between patients, physicians, healthcare providers and other actors in the healthcare system. By enabling real-time sharing of patient data, it allows medical personnel to make beneficial interventions at an early date, with the goal of improving care and boosting cost efficiency. The applications are intended to provide support for people who have chronic diseases or are receiving personalized home care. Additionally, they are expected to increase patient participation in studies (SAP News Center April 19, 2016).

In cooperation with Deutsche Telekom and others, SAP also developed the German Corona-Warn-App in 2020 on behalf of that country's federal government. This software program enables citizens to notify other app users if they have been diagnosed with COVID-19 (Federal Ministry of Health 2021a; SAP News Center June 17, 2020).

SAMSUNG

Samsung Health App

Samsung Gear Fit2 Pro

Samsung Galaxy Watch

Samsung My BP Lab

Samsung Smart TV-Plattform

Rehabilitation program NEJM Catalyst

SAMSUNG's Health app identifies daily activities and habits, and analyzes them with the aim of helping users improve their nutrition and live a healthier lifestyle. It includes a pedometer, an analysis of eating habits, and a sleep and stress tracker. In addition, the app includes exercise programs focused on weight loss and increasing endurance. There is also a news feed that offers personalized information on health topics (Google Play Store 2021d). The Samsung Gear Fit2 Pro is a wristband that records and displays vital-sign data via the Samsung Health app (Samsung 2021a).[50]

The Samsung Galaxy Watch and Galaxy Watch Active2 are smartwatches that include an accelerometer, a barometer and a heart rate monitor, among other features.[51] Thus, the devices can monitor workouts, record and display the user's progress, and compare the results with those produced by other users (Samsung 2020). Samsung

46 Users then see an evaluation of their communication patterns in the app, with the idea that they can learn how to communicate better and more positively (Mühlroth 2020).

47 Users can view the 3D body-fat model in the app, and test how they would look with different body-fat percentages (Mühlroth 2020).

48 U.S. life insurance company John Hancock has already integrated Amazon Halo into its Vitality Program. Participants in the program receive a free three-year membership to Halo. The Vitality Program is focused on helping people live more active lifestyles and improve their overall health. It also includes wearables from other tech companies (Amazon August 27, 2020).

49 For example, Amazon Halo users can transfer data on their activities from Halo to the WW app, and have this converted into so-called FitPoints, which in turn can be counted toward the calorie balance in the diet app (Amazon August 27, 2020).

50 In addition, it has a built-in GPS feature and a music player. The Gear Fit2 Pro also has additional apps available that derive from a collaboration with U.S. sporting goods manufacturer Under Amour. These include MapMyRun (which records jogging routes) and MyFitnessPal (which tracks calorie consumption) (Samsung 2021a).

51 The watch also includes a "running coach" that provides exercise advice, along with a feature that invites users to practice breathing techniques in order to handle stressful situations more effectively (Samsung 2020).

held an 8 % share of the global smartwatch market in 2021, making it the third-largest supplier (Koetsier 2021). Other analysts estimated Samsung's Q1 2021 share of the global smartphone market at around 19 %, making Samsung the second-largest provider after Apple, which had a market share of around 24 % (tagesschau.de 2021a). Some sources note that Samsung took over the position of smartphone market leader in the third quarter of 2020 with a global share of 23 % (Beltrame 2020), while others called it the second-largest provider in the second quarter of 2021, with a 24 % share (GoogleWatchBlog 2021).

Working in partnership with NEJM Catalyst, Samsung has also developed a technology-supported, evidence-based rehabilitation program for heart-attack patients. This program can be loaded onto smartphones and connected to specially configured wearables (Swaney 2019).

Samsung's My BP Lab is both an app and a study. The app measures the users' stress in everyday life, along with associated physical reactions such as blood pressure and heart rate, by means of the optical sensors built into the Samsung Galaxy S9 and S9+ phones. App users are invited to participate in three-week studies being conducted by the University of California, San Francisco (UCSF) (Samsung February 26, 2018) (→3.5).

The Samsung Smart TV platform is an application designed for the company's Smart TV. For example, the company has struck partnerships that give Samsung Smart TV users free access to health and fitness services such as the Calm app's meditation programs or the Fitplan app's workout programs (Reid 2020; Fitplan 2020).

Samsung is collaborating with American Well (Amwell) on a telemedicine platform (LiveHealth Online) accessible within the Samsung Health app, which is available through many Samsung devices. For example, the platform offers an "Experts" feature that allows users to engage in video consultations with Amwell physicians (American Well April 24, 2017; Meskó et al. 2020: 54).

HUAWEI

Huawei Health App

HUAWEI's Health app provides patients and users with professional guidance regarding physical activities. It mainly supports running-based sports (Google Play Store 2021c).

ALIBABA

My Health Service

Alipay Health Code

ALIBABA has launched My Health Service, a free online medical advisory service intended to ease pressure on hospitals during the COVID-19 pandemic, according to the company's own statements. Users can directly access the advisory service via the Taobao shopping platform or the AliPay payment service, and view real-time pandemic data provided by China's National Health Commission. According to Alibaba, hundreds of doctors from across China offer their services through the app. In January 2020, around 90 % of the questions submitted were related to the prevention and treatment of COVID-19 or pneumonia (Xinhua January 27, 2020).

Alibaba's Alipay Health Code app has played a role in the Chinese government's pandemic-management programs. Specifically, it has served as a means of controlling citizens' daily lives and mobility during the COVID-19 era, as it transmits a user's health status using three color categories and integrated quick response (QR) codes.[52] However, according to critics, there has been no precise explanation identifying exactly what data is used to assign users to

52 A green code allows unrestricted mobility. Yellow codes can result in seven days of home isolation, while red codes trigger a two-week quarantine (Mozur et al. 2020).

the different color categories. The New York Times has called this a mass experiment in the use of data to regulate the individual behavior of citizens. The app dictates to users whether they will be quarantined or barred from using subways and visiting other public spaces due to a suspected COVID-19 infection (Mozur et al. 2020).

TENCENT

Tencent Health in WeChat

Digital Health Card

Covid-19-Health-Tracing-App

Tencent Medipedia

TENCENT Health, a service platform within the WeChat app, attracted more than 1 billion active users during the first quarter of 2021 (Iqbal 2021). Launched in 2019, it allows patients and users to engage in online medical consultations, make appointments, and access health information and other health services. The platform is expected to be expanded gradually to different regions in China. The WeChat application allows Tencent to reach a total of 500 million insured people. Users can also pay for hospital stays and medication using WeChat Pay. According to Tencent, nearly 10,000 medical institutions support payments via WeChat. WeChat's Digital Health Card is expected to function analogously to the Chinese Health ID Card, recording medical data from various hospitals and other medical facilities. According to Tencent, the company is promoting this Digital Health Card so as to enable the public to receive the best online and offline patient care (Tencent 2019).

Tencent has also embedded a COVID-19 Health Tracing App in WeChat, with high school and college students in China serving as its primary target market. The tool is intended to calculate risk assessments as students go back to school. This is done by asking the user to answer questions about his or her body temperature, possible conspicuous symptoms, and whereabouts over the past two weeks. After assessing the answers to these questions, the app outputs a color-based QR code on the smartphone. According to Tencent, the app allows educational institutions to check on their students' health statuses (Li and Goh 23.03.2020; Müller 2020).

Tencent Medipedia is a health information sharing platform established in 2017. It provides users with information on the prevention, diagnosis and treatment of diseases, including issues having to do with rehabilitation. The content is conveyed through texts, photos, videos, 3D visualizations and AI-based assistants. The platform has a partnership with WebMD, an international healthcare information platform (Tencent 2019).

Tech giants have developed a wide variety of network-linked wearables in forms such as smartphones, smartwatches, fitness trackers and wristbands, as well as countless health apps including medical and lifestyle apps, all of which can be used to collect and process vast amounts of health-related data in real time. They are designed to monitor vital parameters, including the recording of electrocardiograms. They enable patients and users to participate in research studies, and open up the possibility of online medical advice and behavioral monitoring. During the coronavirus pandemic, they have been used to generate automated notifications when a user may have come into contact with infected individuals, as well as to restrict access to public transportation and other facilities based on health status.

The tech giants' wearables and apps aimed at patients and users have to date focused primarily on the lifestyle, wellness and prevention markets.

Globally, around 445 million wearable devices were sold in 2020 (Tenzer 2022a; IDC 2021), with the forecast for 2024 rising to around 632 million units (Tenzer 2022b; IDC 2020). The leader in this market is Apple, which had a global market share of around 34 % in 2020 (IDC 2021). In the second quarter of 2020, approximately 656 million health and fitness apps were installed. Revenue in the segment for the same period was $ 328.5 million (Chapple 2020). According to 2018 forecasts, the market for mobile health apps was expected to grow to $ 11.2 billion worldwide by 2025 (BIS Research 2018). However, by 2020, the size of the global m-health app market was already estimated at $ 24.93 billion (Fortune Business Insights 2022).

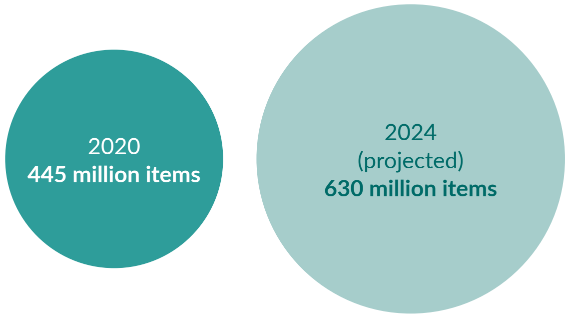


FIGURE 7:
Global sales of wearables
Source: Authors. Data: IDC 2020; IDC 2021, Bertelsmann Stiftung

3.2.2 VIRTUAL ASSISTANT SYSTEMS AND DIGITAL AVATARS

Patients and users can also make use of virtual assistant systems and digital avatars. This latter category can be defined as "computer-based artificial and graphical representations of a person that assist people with a task" (Angerer et al. 2019: 12). Other types of virtual assistant systems may not mimic a human to the same degree. Perhaps the most widely known such services today are the voice-based digital assistant systems in smartphones and other wearables, which are based on automated speech recognition and voice analysis processes (Kalis et al. 2018; German Ethics Council 2017b: 76). Numerous health applications for such tools have already been developed[53] or are conceivable, from reminders to take medication to the provision of medical information to recommendations of various kinds (Krüger-Brand 2020; Champeaux 2019). In the following section, we outline some of the tech giants' activities in the field of virtual assistant systems and digital avatars.

53 A number of the tech giants' products and applications in the field of virtual assistant systems and digital avatars have already been replaced by newer innovations or pushed out of the market by other developments. For example, Google Allo was an instant messaging service that had implemented the Google Assistant intelligent assistant function. The Smart Reply function also answered users' questions. Allo gained new information as it monitored users' behavior, which helped it in turn become more personalized (Holland 2016a). Meta's (formerly Facebook's) M was a virtual assistant that could automatically carry out tasks for users, including such chores as purchasing items and making reservations (Kelly 2015).

AMAZON
Amazon Alexa
Amazon Echo

AMAZON distributes its AI-based voice assistant Alexa, which accounted for 69 % of smart speaker sales in the U.S. market in the period from 2016 to 2021 (Bishop 2021a).

Some analysts predict that it could become the digital doctor of the future. Amazon intends to use Alexa to help improve healthcare, for instance by providing immediate services such as identifying mild illnesses at home and making treatment recommendations that could save patients and users from having to consult a doctor (Meskó et al. 2020: 34-37). Alexa is already being used in studies to increase the physical activity of patients who have suffered or are suffering from oncological conditions, by providing them with guidance and support from the voice assistant in their recovery process (Hassoon et al. 2020; Hassoon et al. 2018). In addition, Alexa has been used in a study that relied on the voice-activated service to facilitate the transfer of health data to electronic databases by medical and nursing staff (Bhatt 2020).

In 2018, Amazon established a team tasked with improving Alexa's ability to provide healthcare support to chronically ill and elderly people. The company's collaboration with German startup Ada Health[54] gives it access to a large AI-based database of diseases and symptoms, which will be used to infer users' health statuses based on their self-reported symptoms (Meskó et al. 2020: 37). Amazon holds a patent for Alexa relating to the use of voice analysis to deduce the health status of patients and users (Krüger-Brand 2020: 377).

The multifaceted use of the Alexa digital voice assistant could allow Amazon to develop new healthcare business models by analyzing a large amount of voice data from different users (Hecking 2019).

Developed in collaboration with Boston Children's Hospital, the Alexa-enabled MyChildren's app assists parents and medical staff in conducting home-based post-operative care for children who have recently undergone heart surgery (Meskó et al. 2020: 37; Hecking 2019; Kohlhagen 2019). Specifically, parents can use MyChildren's to view their children's health records, send messages to care teams, and access other services related to their child's hospital care, such as a payment feature and appointment management functions. Another Alexa application, the KidsMD digital health platform, provides general information on diseases and medications.

Amazon is also working with pharmaceutical company Merck & Co. on an Alexa-based program to help diabetes patients manage their conditions, for example by providing dietary advice and monitoring self-reported glucose levels (Luminary Labs LLC. 2017).

One example of Alexa's potential applications in Germany is the TK Smart Relax service offered by the Techniker Krankenkasse (TK) health insurance fund. This provides TK customers with access to an Alexa function that plays soothing sounds from nature or guides them through relaxation exercises (Krüger-Brand 2020: 377).

Alexa is also used as a voice-based assistant to access medical information. For example, since 2019, people in the United Kingdom's state-run health insurance system have been able to post their medical questions directly to Alexa through a project carried out in partnership with the U.K. National Health Service (NHS) (DHSC 2019). To answer these questions, Amazon Echo,[55] the smart Alexa home device, searches through the information that has been published on the NHS website (Lake 2019).

54 Ada Health operates the Ada app, which lets patients and users seek medical advice via an AI-based chatbot. This system asks users about their symptoms and complaints, and uses the answers to derive possible diagnoses and further recommendations (Ada 2021).

55 Industry analysts estimate that over 20 million U.S. households had more than one Amazon Echo device as of June 2021 (Bishop 2021a).

GOOGLE Duplex supports a new virtual assistant feature called Google Assistant. Google Duplex has been in a test phase since May 2018. It has already been introduced in parts of the United States and is increasingly being expanding into other international markets (including Canada, the U.K. and Australia). Using Duplex, Google Assistant can use a human-sounding voice to contact businesses or doctors and make appointments, for example. The use of AI-powered assistants is expected to save time resources in the healthcare sector, while also streamlining planning processes (Tillman 2021; Catley 2018).

The COVID-19 Pathfinder, created by Google subsidiary Verily Life Sciences (Verily), provides information about the coronavirus, helps patients and users understand their symptoms and the potential severity of the disease, and provides personalized information. This information is drawn from trusted sources such as the Centers for Disease Control and Prevention (CDC), the World Health Organization (WHO), Johns Hopkins Medicine, the American Lung Association, the American Heart Association (AHA), and the American Diabetes Association (ADA). The application is designed for organizations and companies (including hospitals), and can be integrated into their websites (Verily 2021b).

Google Nest (formerly Google Home) is part of Google's smart home series of products. The Google Nest Hub is a smart home tablet that can be operated via gesture and voice control, and can monitor and analyze sleep patterns using sleep sensors, among its other capabilities (Google Store 2021; Amadeo 2019) (➔3.4.9).

GOOGLE / ALPHABET

Google Assistant

Google Duplex

Covid-19-Pathfinder

Google Nest

APPLE Siri was introduced in 2011 along with the iPhone 4s, and was the first voice-controlled assistant in the virtual assistant market (Yoffie et al. 2018; Frommer 2010). It adapts to users' individual speaking styles, searches and preferences, and thus personalizes the results it provides in the form of recommendations, answers to questions, links to other services and other actions. The software uses a natural language processing (NLP) algorithm for its speech analysis. The more information the algorithm processes, the more powerful the software becomes (Yoffie et al. 2018). Siri shortcuts can be used by patients and users to perform tasks such as tracking and analyzing daily activities, such as fluid intake and hygiene tasks. The software then provides recommendations based on these patterns (Apple March 01, 2019).

APPLE

Apple Siri

SAMSUNG developed an AI-powered digital avatar in 2020, in what it has called an "artificial human" project. The company has said the avatars can feel and empathize with conversations – just like real people. The associated AI technology is called NEON, and was developed by the Samsung spin-off STAR Labs. The company has indicated an interest in using these avatars as service providers in the healthcare sector (Lever 2020).

SAMSUNG

Artificial Human

NEON

TENCENT
Babylon Chatbot

TENCENT has partnered with Babylon Health[56] to provide the Babylon Chatbot, an AI-powered virtual assistant, within the Babylon Health app (Choueiri et al. 2020: 6). According to Babylon Health, the chatbot can detect most health problems as well as a primary-care physician. The service provides patients and users with possible diagnoses, after which they can take further steps themselves as needed (Babylon Health 2021).

Virtual assistant systems and digital avatars offer tech giants the opportunity to collect a huge range of health-related data from within users' everyday lives. Numerous different providers' voice assistants in particular have enabled a wide range of AI-based services that, as in the case of wearables and apps, have to date focused largely on the lifestyle and prevention markets, especially in the home environment. Digital assistant systems open up a rich spectrum of possible health-related services. For example, they could provide users with initial medical screenings, supply medication recommendations and order any medications desired, and offer support for home-based post-operative care.

Globally, the size of the virtual assistant market was $ 5.82 billion in 2020. Analysts have forecast a growth rate of 28.5 % between 2021 and 2028 (Grand View Research 2021), which would produce a projected market size of $ 51.9 billion in 2028. It has been estimated that 8.4 billion digital voice assistants would be in use by 2024, a quantity that exceeds the size of the world's population (Business Wire 2020; Moar and Escherich 2021). In Germany, around one-third of the population were using voice assistants by 2019 (FAZ 2019); by 2020, this figure had risen to just under one-half (Gehm 2020).

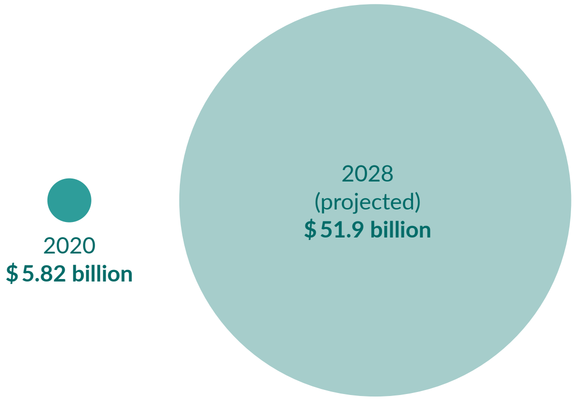


FIGURE 8: **Global market volume of virtual assistants**
Source: Authors. Data: Grand View Research 2021, Bertelsmann Stiftung

56 Babylon Health is a U.K.-based digital health startup. Its goal is to use AI to detect diseases and assess health-related conditions and implications after the input of user data (Sturman 2020). Babylon Health and Tencent engaged in their first joint project in 2018. Tencent offered Babylon Health the opportunity to deploy its AI-based service on WeChat. The two companies did not enter into licensing agreements regarding user data (Ram 2018). In 2021, Babylon Health and Tencent announced that they had ended their partnership after failing to agree on the allocation of the venture's shares (Thomson 2021).

3.2.3
AUGMENTED REALITY (AR) AND VIRTUAL REALITY (VR)

Augmented reality (AR) and virtual reality (VR) have been described as "computer-generated realit[ies]" (Angerer et al. 2019: 12). In 2020, Apple CEO Tim Cook singled out augmented and virtual reality as one of the tech giant's most important future areas of business, stating that augmented reality (AR) would become Apple's "next big thing" (Köbe 2020).[57] In contrast to the applications discussed above, however, few examples within this area have actually reached the market.

SAMSUNG offers a virtual reality solution with its Samsung Gear VR headset. In a joint project with IrisVision, the company developed software for the headset that can fill in missing areas of the visual field for people suffering from age-related macular degeneration. Samsung says this will make a vital contribution to expanding older people's independence. The Samsung Gear VR headset has been used for research purposes in a partnership with Cedars-Sinai Medical Center in Los Angeles and appliedVR, a consulting and contracting firm. In 2018, the project completed a randomized trial with 120 patients suffering from acute pain (Rhew 2018).

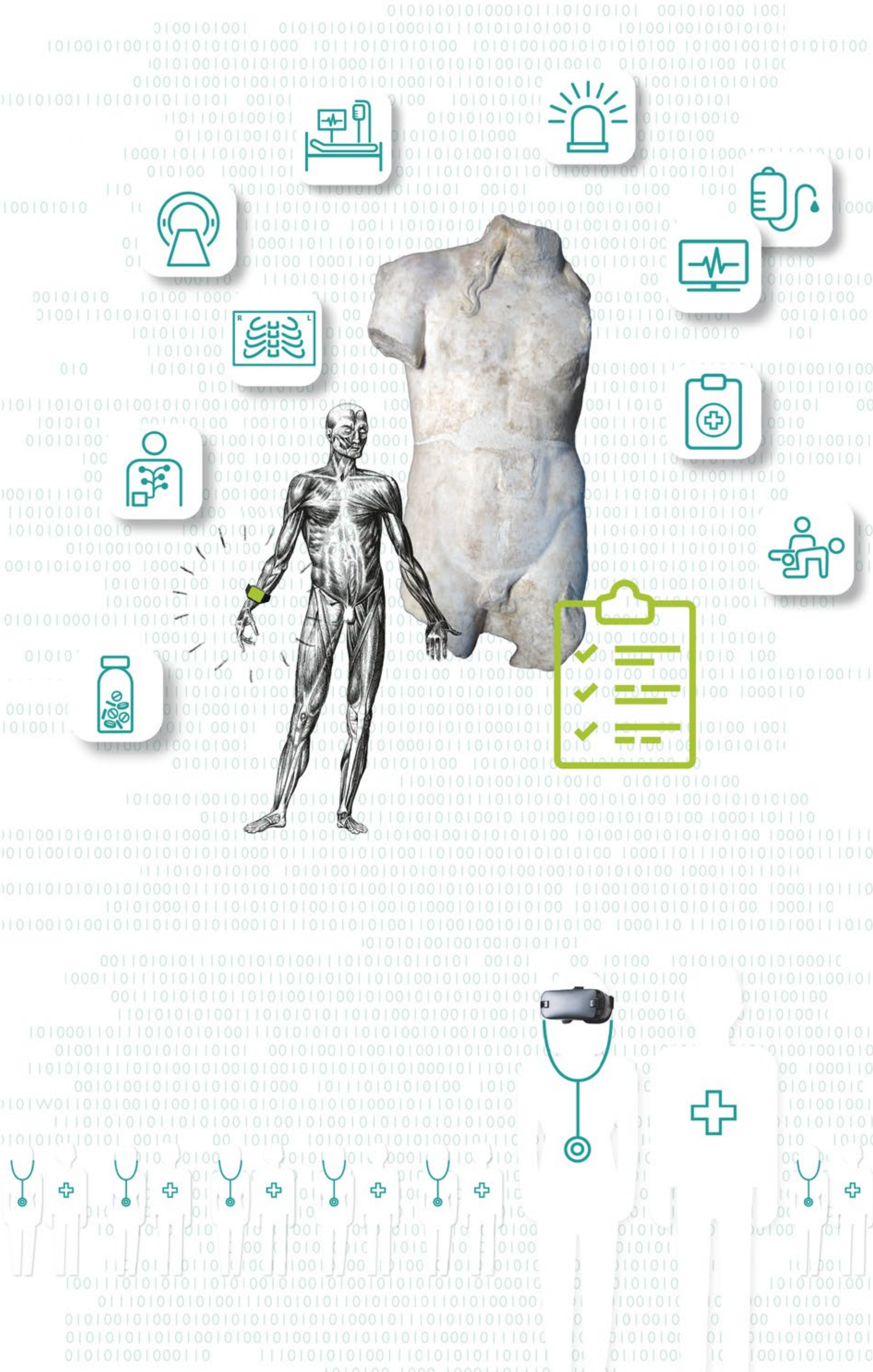
SAMSUNG
Samsung Gear VR Headset

Only a few augmented reality (AR) and virtual reality (VR) products aimed at patients and users have as yet been released.

3.2.4
SUMMARY

Tech giants offer patients and users an entire universe of health-related products and services. The focus to date has been on wearables, apps and virtual voice assistant systems. Most of these products and services have addressed the wellness, lifestyle and prevention markets. They typically involve the collection and processing of a huge amount of digital data from different areas of life, and are usually associated with AI applications. They help patients and users perform tasks such as obtaining health information, networking with service providers, recording health data, and treating certain diseases and conditions. Strikingly, Asian tech giants in particular have used their applications to monitor and control behavior, which includes limiting access to public areas. This is done by linking the collection of data to numerous aspects of everyday life up to and including basic payment functionalities. With this wide range of offerings and their significant market penetration, tech giants may well be able to raise user awareness regarding the importance of maintaining and improving health as an important part of daily life, and thus enhance the importance attributed to prevention. The ethical issues associated with this phenomenon are discussed in chapter → 4.

57 As yet, Apple has given no more specific indications of future planned products in this area (Köbe 2020).



3.3
TECHNOLOGIES FOR HEALTHCARE PROFESSIONALS

This chapter focuses on the technologies and applications designed for use by healthcare workers. This includes all health professionals such as long-term care workers, nurses, clinicians and medical staffers, psychotherapists, physiotherapists, occupational therapists, music and art therapists, ecotrophologists, emergency medical technicians and many others.

3.3.1
WEARABLES AND APPS

Having provided basic comments regarding wearables and apps in healthcare in section →3.2, in the following, we provide examples of the tech giant offerings that target professionals working in the health sector.

GOOGLE / ALPHABET

Streams

Automated Retinal Disease Assessment

Google Health Search

The Medical Google / iSearch Science

Care Studio

GOOGLE's corporate unit DeepMind Health has developed the mobile healthcare app Streams, which applies AI technology. The app keeps clinicians informed in real time of their patients' condition by tracking and assessing app-based test results and can, for example, provide assistance in predicting cases of acute renal failure (DeepMind July 31, 2019) (→3.4.9).

Together with a group of opthalmologists, Google Health developed an AI-assisted diagnostic imaging application (Automated Retinal Disease Assessment, ARDA) for use in evaluating retinal fundus photographs to detect diabetic retinopathy in patients (Google Health n. d. e; Gulshan et al. 2016).

Google's Health Search engine is being developed to structure health data and information in electronic health records (EHR) and other sources of patient data provided by devices such as Fitbits in such a way as to improve their accessibility and searchability for health professionals. The tool will eventually be made available to patients as well, and is intended to facilitate medical progress, strengthen prevention, and increase life expectancy (Rawal 2020; Google Health n. d. b).

The Medical Google / iSearch Science, an app from U.S.-based software firm Best Surgical Education, LLC, combines Google Search with natural language AI to identify current studies, research and knowledge regarding a given issue or clinical question. By automatically adding search-specific search terms, the app achieves a broader range of results. The app also aids users in identifying the most recent and relevant scientific studies (Best Surgical Education 2021, 2020).

Google's Care Studio is a U.S. Health Insurance Portability and Accountability Act (HIPAA)[58]-compliant software designed to support clinicians by streamlining healthcare records and information. Clinicians can, for example, use the software to quickly locate specific information in a patient's health record or to create visualizations of data regarding a specific set of patients. There is also

58 Act of Aug. 21, 1996, Pub.L. 104–191, containing rules relating to privacy set forth in 45 CFR 160, 162, and 164.

a Care Studio app that allows users to view all information on their smartphone (Google Health n. d. a).

PHILIPS

Philips HealthSuite

Philips eCare-Coordinator

Philips HeartModel

Philips Dynamic HeartModel

PHILIPS’ HealthSuite includes the app-based Philips eCareCoordinator, which provides outpatient care staff real-time access to patient health data so that they can, for example, make adjustments to therapy measures when needed (Philips 2021d) (→3.2).

Philips’ HeartModel and its successor Dynamic HeartModel are clinical applications that enable cardiologists to assess cardiac functions relevant to the diagnosis and treatment of patients with cardiovascular disease. The application uses 3D speckle technology to track individual frames throughout the entire cardiac cycle. Additional measurements of items such as muscle mass help increase diagnostic confidence and lead to more reliable heart function assessments (Philips 2021a, 2018a).

Philips offers online clinical seminars, in English, for physicians and hospital administrative staff on issues relevant to treating COVID-19. In response to the pandemic, the company has also created a portal for healthcare professionals through which they can access COVID-19-related resources such as instructional videos on proper disinfection techniques as well as information regarding a variety of COVID-19 treatment solutions (Philips 2021h).

SIEMENS

AI-Rad Companion

AI-Pathway Companion

Mitral View Educational App

Siemens Syngo.via

Siemens Healthineers Teamplay Digital Platform Connect

Digital Ecosystem

Healthcare Provider Directory

Electronic Health Record

Terminology Server

Adaptor Set

Naeotom Alpha

SIEMENS has developed several AI-based solutions that are designed to support healthcare professionals by automating complex procedures. These include the AI-Rad Companion, a cloud-based solution to support routine medical imaging activities (Siemens Healthineers 2021b), and the AI Pathway Companion, which is designed to optimize disease-specific treatment pathways (Siemens Healthineers 2021a).

Together with the U.S. company Abbott,[59] Siemens developed the Mitral View Educational App for use in cardiology and heart surgery. The app is designed to educate clinicians who use 3D TEE (ultrasound diagnostics) for visualizations of the heart during mitral valve procedures by demonstrating the different positions and angles in the imaging process. It provides images of a normal mitral valve and those of primary and secondary mitral regurgitation (Siemens Healthineers 2021l, 2021c).

Siemens’ syngo.via, an intelligent imaging software for use in radiology, is designed to streamline image assessment and reporting workflows in areas such as pulmonology and cardiology. Through the platform syngo.via OpenApps, users have access to innovative clinical apps from Siemens Healthineers and its partners (Siemens Healthineers 2021s, 2021t).

Siemens Healthineers’ teamplay digital platform connect is a platform designed to foster interoperability across departments and institutions in the healthcare sector and to promote the exchange of information between actors such as healthcare providers in compliance with international security standards. The electronic health record (EHR) is a core staple of the platform’s focus. The platform also provides users access to AI-powered applications for use in data-driven health decisions. Patients, too, are to be given access to their personal medical and clinical data. The platform is the

59 In addition to healthcare technologies and the early identification of relevant global healthcare trends, Abbott focuses on health diagnostics, cardiovascular therapy, medical devices, diabetes management, medical nutrition and the development of generic drugs (Abbott 2021).

result of a collaboration between Siemens Healthineers and IBM, with Siemens Healthineers maintaining control over the patient registry and IBM managing the document index. The platform will also be opened up to third-party providers and their applications according to the company (Siemens Healthineers 2021u; Siemens Healthineers and IBM Dec. 8, 2020).

Siemens Healthineers Digital Ecosystem is a cloud-based platform that integrates and interconnects medical data with service providers, payers, patients and Siemens' partners to create a network able to optimize diagnostics and treatment (Siemens Healthineers 2021g; Pfannstiel et al. 2020: 100).

Siemens Healthineers is also developing several other e-health solutions. These include the Healthcare Provider Directory (HPD), an electronic health record (EHR), a Terminology Server (TS), and an Adaptor Set (AS), which facilitates the interoperability of standardized healthcare networks (Siemens Healthineers 2021i). The EHR from Siemens Healthineers can be used as a platform by healthcare providers or companies and offers patient-related data exchange. The application also provides for patients to have access to their own EHR (Siemens Healthineers 2021i).

Siemens Healthineers developed the first-ever photon-counting computed tomography system for clinical applications, garnering the division's senior staff a nomination for the German Future Prize (Siemens Healthineers 2021x). The technology has enabled immense advancements in medical imaging, such as ultra-high resolution scans and reduced radiation exposure levels. In late 2021, Siemens Healthineers unveiled Naeotom Alpha, the world's first photon-counting CT scanner, which has been approved in the United States and Europe (Siemens Healthineers 2021y).

SAP

Betten-Management@SAP

SAP Connected Health Platform

SAP's "Betten-Management@SAP," a bed-management solution developed during the COVID-19 pandemic for the Rhine-Neckar region and the German city of Heidelberg, makes it possible to coordinate hospital beds in real time and thus streamline patient transferals and the use of intensive care resources. An interactive geomap helps medical staff coordinate the processes along (SAP June 25, 2020).

SAP's Connected Health Platform (formerly SAP Foundation for Health), which is based on SAP HANA Cloud, supports various applications in precision medicine and research. It allows for large amounts of data from different sources to be processed and analyzed in one system (Zabłocka 2017).

HUAWEI

Huawei Cloud

AI-based services

HUAWEI Cloud has provided several AI-based services during the COVID-19 pandemic. These include, for example, a screening service that can help healthcare professionals better assess CT scans of a patient's lungs by automatically segmenting lung lesions and measuring lesion volume (Huawei Cloud 2021b).

The wearables and apps offered by the tech giants with healthcare professionals in mind have so far focused primarily on accessing patient data, monitoring disease-relevant parameters, diagnostics (particularly AI-assisted image analysis), as well as treatment recommendations and providing an overview of efficient treatment pathways. Storage systems and analytic platforms are opening up access to disease-related scientific expertise and large data sets, which can be used to develop proprietary applications. Apps also foster networking activities between the various players in the healthcare sector and optimize care processes.

3.3.2 VIRTUAL ASSISTANT SYSTEMS AND DIGITAL AVATARS

For a basic introduction to the use of virtual assistance systems and digital avatars in healthcare, please refer to the comments made in →3.2. A curated selection of tech giant efforts targeting healthcare professionals in this area is provided in what follows.

AMAZON
Amazon Alexa

AMAZON's voice-activated assistant Alexa is taking on tasks in the Smart Hospital Room Pilot Project at Los Angeles' Cedars-Sinai Health Center in trial scenarios whereby patients can communicate hands-free with medical staff and control devices such as TVs (Meskó et al. 2020: 37). New York provider Northwell Health has also begun equipping hospital rooms holding COVID-19 patients with Amazon Echo Shows devices, which allow caregivers to monitor and connect with patients remotely (Meskó et al. 2020: 38) (→3.2).

IBM
IBM Watson Health
Watson Assistant
IBM Medical Sieve

IBM's Watson Health offers an entire ecosystem of technologies, applications and consulting services that are designed to help various actors in the healthcare sector improve healthcare while rendering it more efficient and organizations more resilient. Examples include IBM Watson for Genomics, IBM Watson Oncology, IBM Watson for Drug Discovery, Watson Care Manager and Watson Assistant (IBM 2021h).

IBM's chatbot Watson Assistant can be used as a virtual assistant that provides automated replies to COVID-19-related questions relevant to healthcare facilities. As an AI-based tool, the assistant draws on trusted information sources to respond to pandemic-related questions involving issues such as government support and information regarding COVID-19 symptoms. Responses provided by the assistant are adapted to individual contexts, such as location (IBM 2020b; Jones 2020). During the COVID-19 pandemic, the tool has been applied in at least 22 countries, including Poland (i. e., the Polish Ministry of Health) and the United States (i. e., in Austin, Texas) (Meskó et al. 2020: 37-38).

IBM's Medical Sieve project is developing a cognitive assistance system to aid radiologists in clinical decision-making. The system uses vast data sets of digital and ultrasound imaging and documentation in an effort to detect anomalies. Diagnostics involving the interpretation of imaging are supported with a summary of information from the patient's record, which is generated by the IBM Watson Patient Imaging Synopsis, and thus provides a clinical context that is relevant to the decision-making process. The core idea of such systems is to battle cognitive fatigue among physicians by providing clinical decision support that allows for tailored-to-the patient treatment. These systems are thus also intended to provide a reprieve from repetitive activities such as the analysis of imaging material (IBM 2021e; Kohn et al. 2014)

.

INTEL and IBM, as well as other companies such as Kaiser Permanente, are partnering with Intelligent Digital Avatars Inc. (iDAvatars), the startup behind the avatar "Sophie" (Dill 2018), which features human-like qualities and is designed to evaluate a patients' health records while recording its interactions with them. Bayer HealthCare, for example, has already begun using Sophie with patients requiring pain management (Dickinson 2015). Another avatar, "Holly," which was developed by CodeBaby, a company that acquired iDAvatars in 2016 and whose software is based on IBM's Watson, can be used to walk patients through a health check-in (Dill 2018; CodeBaby 2020, 2021).

INTEL
Sophie
Holly

GOOGLE is partnering with Suki AI, Inc. by implementing the AI-powered and voice-enabled digital assistant Suki within the Google Cloud. Designed to relieve healthcare professionals of administrative tasks, Google claims that working with Suki reduces the amount of time spent on completing health data documentation by 76 %. Suki understands natural language and can perform tasks such as taking notes and retrieving information from electronic health records (EHR) (Google Cloud 2021c; Suki AI 2019).

Google Glass is a wearable device used in healthcare and other areas as a virtual assistance system (Google Glass n. d.; Sutter Health 2021). In the healthcare sector, Sutter Health is equipping clinicians with the technology so that they can spend less time on documentation and more on caring for patients. This is made possible through another partnership between Sutter Health and the documentation platform Augmedix (Sutter Health 2020).

GOOGLE / ALPHABET
Suki
Google Glass

MICROSOFT's (Azure) Health Bot Service, a cloud-based platform, is designed to help healthcare organizations and institutions such as medical facilities, pharmaceutical companies and health insurers integrate virtual assistants and chatbots that provide information and services. Designed to provide patients and users a conversational healthcare experience, the service links AI with natural language capabilities in providing access to relevant evidence-based healthcare services and information (Microsoft 2021c; Microsoft Research 2021a).
In the context of the COVID-19 pandemic, healthcare organizations in the United States such as the Centers for Disease Control and Prevention (CDC), Providence, Novant Health, and the Virginia Mason Health System, are using the service to provide users with information about the disease and how to assess symptoms, while recommending potential next steps (Microsoft April 4, 2020).

MICROSOFT
Microsoft (Azure) Health Bot Service

SONY
Sony NUCLeUS

SONY's NUCLeUS smart digital imaging platform streamlines the aggregation of high-resolution video content across a hospital network. By making it possible for healthcare professionals to manage, distribute and store 4K, HD, SD and 3D video content across systems, the platform promotes efficiency and improves workflows. Using NUCLeUS can enhance surgical imaging workflows in operating rooms during advanced surgical procedures. In addition to allowing surgeons to share and discuss images and footage with colleagues remotely, it also allows for the real-time broadcast of intricate surgical procedures to students in classroom environments, as is currently the case at Liverpool's Alder Hey Children's Hospital. Sony's NUCLeUS is also in use at St. Jansdal Hospital in the Netherlands, where it saves surgical staff time, makes remote consultations a reality, and streamlines the coordination and use of equipment (Meskó et al. 2020: 54-55).

NVIDIA
Digital Human Creation

NVIDIA is researching technologies to improve and expedite AI-powered digital human creation. In targeting this goal, NVIDIA uses natural language processing (NLP) technologies such as Ensemble Health AI to construct conversations between real and digital humans. NVIDIA sees great potential for AI-powered digital assistants in healthcare and surgeons in particular, as the technology will allow them to run through patient care scenarios, including surgical procedures, as often as needed (Yuen 2021).

PHILIPS
Digital Twin Technology
Adaptive Intelligence

PHILIPS is creating digital twins, a technology that is being powered by AI (→3.5). The company speaks of "adaptive intelligence," emphasizing the importance of human knowledge and judgment in situations where the technology is applied (Philips 2018c). One example is Philips' avatar-based tool for monitoring a patient's vital signs during surgery that has been tested with a Google Glass headset. The data displayed on the peripheral area of the glasses is color-coded, which allows the person performing the operation to identify clinically relevant information without having to focus specifically on precise numbers (Pfarr et al. 2019).

ALIBABA
ET Medical Brain
Doctor You
DAMO Academy

ALIBABA Cloud launched the ET Medical Brain service in 2017. Designed to support healthcare professionals, the virtual assistant uses AI in medical imaging to improve, for example, tumor diagnostics.

The diagnostic system Doctor You, which is used in early cancer detection procedures, is another example of the service's application (Bajpai 2017). Alibaba's research institute, DAMO Academy, developed an AI-enabled system in early 2020 to diagnose COVID-19 within 20 seconds and with 96 % accuracy. Using CT scans of the lungs, the system is designed to detect infection with the virus. The system's deep-learning algorithm was trained with more than 5,000 confirmed COVID-19 cases according to Alibaba's news hub Alizila (Li 2020).

TENCENT
AI Medical Innovation System
Tencent Miying

TENCENT established the AI Medical Innovation System (AIMIS), an AI-powered medical imaging service, in partnership with the Chinese government. The service feeds medical images of a patient's tissue into its AI which, according to Tencent, determines whether the tissue is abnormal in less than four seconds. AIMIS delivers 90 % accuracy in diagnosing esophageal cancer, 95 % in pulmonary sarcoidosis, and 97 % with diabetic retinopathy, and is said to be a powerful aid for clinicians when it comes to making the right diagnosis (The Medical Futurist 2019; Meskó et al. 2020: 61).

Tencent Miying, a product of Tencent Youtu Lab, is expected to support more than 100 hospitals in China with oncology diagnostics, help reduce workloads among medical staff and increase the precision of clinical diagnoses (Tencent 2019).

The tech giants are also offering virtual assistance systems for application in healthcare professions. These systems are primarily intended to optimize each step in the treatment process, increase efficiency in routine activities, reduce administrative burdens, and enhance the resilience of healthcare organizations.

3.3.3 AUGMENTED REALITY (AR) AND VIRTUAL REALITY (VR)

Introductory considerations regarding the use of augmented reality (AR) and virtual reality (VR) in healthcare were presented in section →3.2. Below, a selection of tech giant products and services in this area that target healthcare professionals is presented.

META (formerly Facebook) offers its Oculus Quest virtual reality (VR) goggles for use in the world of gaming.[60] In an initial collaboration with Children's Hospital Los Angeles (CHLA) in the United States, the product will be applied in mock training sessions involving rare but life-threatening scenarios, particularly in pediatrics, to help medical staff and students prepare for emergencies (Kohlhagen 2019: 53; Oculus 2018).

META (formerly Facebook)
Oculus Quest

MICROSOFT'S augmented reality (AR) product is the HoloLens headset (Kohlhagen 2019: 53; Meskó et al. 2020: 29). The company cites applications in the health sector that range from "real-time ultrasound simulations in different parts of the body to the use of 3D deep-learning holograms for birth preparation courses, virtual heart surgery training and interacting with virtual patients" (Kohlhagen 2019: 53). HoloLens is already being deployed in a collaboration with Case Western University in the United States, while software applications for use with HoloLens are being developed in partnerships arranged with companies such as CAE Healthcare and Medivis (Meskó et al. 2020: 29).

MICROSOFT
HoloLens

60 In December 2020, Germany's independent competition authority, the Bundeskartellamt, initiated proceedings against Facebook to review the fact that operating the glasses requires users to have a facebook account, a requirement that was introduced by the company in October 2020 (Bundeskartellamt Dec. 10, 2020).

PHILIPS
Ambient Experience for Healthcare Project

PHILIPS' Ambient Experience for Healthcare Project is the outcome of years of research in design thinking that delivers improved satisfaction among patients and staff as well as more efficient workflows in more than 1,000 projects involving room design solutions (e.g., dynamic lighting, colors, sounds) that are tailored specifically to a facility's needs (Philips n.d. b).

The tech giants offerings in augmented and virtual reality technologies currently find application primarily in the education and training of young medical professionals.

3.3.4 SUMMARY

Increasingly, today's health professionals must deal with large sets of data. AI-based applications that use these datasets provide support in various ways, including assistance with decision-making, optimizing treatment processes, and facilitating the exchange of knowledge and data between various actors in the healthcare system. These applications can help improve the quality of care while easing the burden on healthcare professionals.

In order to achieve these goals, healthcare workers require increasingly stronger digital skills. As healthcare becomes increasingly integrated and digitalized, responsibilities and job requirements are shifting within the health professions. The ethical issues associated with this phenomenon are discussed in chapter →4.

3.4
HEALTHCARE SYSTEM

The following section focuses on those tech giant activities that affect healthcare provision systemically and are thus likely to transform the healthcare system as a whole.[61]

3.4.1
HEALTHCARE CLOUD COMPUTING

The current generation of health-related data is characterized by extreme speed, continually increasing volume and a high degree of complexity (Sha M and Parveen Rahamathulla 2020). Cloud computing serves to organize and manage this vast amount of data and ultimately to improve healthcare. The infrastructure of clouds consists of components for the ingestion, storage and processing of data (ibid.: 1015–1017). Cloud offerings include, among other things, "storage, infrastructure, software, a platform and analytics" (Weichert 2018: 36).

Cloud-based programs that are used in healthcare provision must be in compliance with country-specific regulations, such as the European General Data Protection Regulation (GDPR) or the Health Insurance Portability and Accountability Act (HIPAA) in the United States, to protect patients' sensitive health data. There are numerous public cloud providers in existence that offer solutions for data management within the healthcare system. Among them are many tech giants, led by Amazon, Google and Microsoft, which together have a 68 % share of the European cloud market (current as of 2021) (Martin-Jung 2021). Selected activities of tech giants pertaining to cloud computing in healthcare provision are examined below.

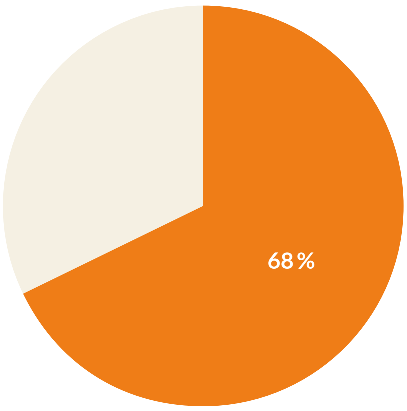


FIGURE 9: **Amazon, Google and Microsoft – share of the European cloud market 2021**
Source: Authors. Data: Martin-Jung 2021, Bertelsmann Stiftung

61 The designations used for the relevant service areas are based on a differentiation and further development of the explanations developed by Kohlhagen (2019: 51).

AMAZON became one of the first companies to introduce a cloud computing solution, called Amazon Web Services (AWS), back in 2006 in an effort to keep up with the rapidly rising volume and usage of data. In 2019, Amazon controlled almost 50 % of the global public cloud market (Meskó et al. 2020: 36; Schulz 2018: 97; Su 2019). In the Q3 2021, AWS was the beneficiary of 32 % of all global expenditures on cloud infrastructure services. These are services that included infrastructure and platforms either as private or shared infrastructure (Canalys 2021). The Subcommittee on Antitrust, Commercial and Administrative Law in the U.S. House of Representatives determined in a report published in October 2020 that the company enjoyed a dominant position in the market. This position, the report notes, comes both from the company's pioneering efforts to establish the technology as well as active efforts to suppress competition (Subcommittee on Antitrust, Commercial and Administrative Law 2020: 319). Numerous public institutions and other companies now rely on AWS, including the U.S.-based Cleveland Clinic, many of which have even developed their own applications based on the platform (➔ 3.4.9). In 2018, AWS introduced the cloud-based service Amazon Neptune Technology, which enables the processing of highly complex linked data (Meskó et al. 2020: 36).

AMAZON

Amazon Web Services

Amazon Neptune Technology

GOOGLE Cloud Life Sciences (formerly Google Genomics) is a Google Cloud product designed to store, process and share large biomedical and genomic datasets in the biological sciences and bioinformatics sectors (Google Cloud n. d.; Meskó et al. 2020: 12) (➔ 3.4.9). Google Apigee Healthcare APIx is a Google Cloud product for the design, protection and publishing of digital interfaces that can be used by hospitals, for example, to connect physicians, nurses and patients through various apps (Google Cloud 2021d). Google Cloud Healthcare API enables the development of healthcare solutions within the Google Cloud that can be used by the clinic and for analytics (Google Cloud 2021a). Google Healthcare Natural Language API analyzes unstructured medical texts with the help of machine learning and transforms it into machine-readable data (Google Cloud 2021b).

Google Workspace, formerly G-Suite, is also a tool that can contribute to simplifying healthcare provision through cloud-based solutions. For example, documents and patient information can be worked on collaboratively in real time using Google Drive (Verbrugghe 2020).

GOOGLE / ALPHABET

Google Cloud Life Sciences

Google Apigee Healthcare APIx

Google Cloud Healthcare API

Google Healthcare Natural Lanuguage API

Google Workspace

APPLE's iCloud can synchronize health data across all of a user's devices. That data can be recorded and processed using Apple's Health App (Apple 2021b).

APPLE

iCloud

MICROSOFT

Microsoft Azure

Microsoft Azure Security and Compliance

Blueprint – HIPAA / HITRUST Health Data and AI

Microsoft Genomics

Microsoft Cloud Healthcare

MICROSOFT Azure Security and Compliance Blueprint – HIPAA / HITRUST Health Data and AI is a cloud-based service used in the healthcare sector. It enables medical institutions, for example, to collect, store and analyze data from patients. The system offers an implementation and automation function and includes step-by-step documentation, a cybersecurity model and additional features for automated cloud implementation (GitHub 2019). In 2021, Azure secured Microsoft a 21 % share of the cloud computing market, making the tech giant the second-largest provider worldwide after Amazon with its AWS solution (Canalys 2021). Microsoft's quarterly revenues increased by 22 % in Q3 of 2021 to $ 45.3 billion, largely thanks to its cloud business. That same quarter, Microsoft Cloud revenues rose by 36 % to $ 20.7 billion (Bishop 2021b).

Microsoft Genomics is also part of the Microsoft Azure cloud service (Microsoft 2017) and is a service of Burrows-Wheeler Aligner (BWA) and the Genome Analysis Toolkit (GATK) for the secondary analysis of genomic data. Areas in which Microsoft Genomics can be applied include cancer treatment and precision medicine (Microsoft Genomics 2018; Microsoft 2017) (→ 3.4.9).

Microsoft Cloud Healthcare includes data models, APIs and integrated healthcare-specific components with a variety of cloud applications and services from Microsoft. The focus is on patient care (arranging appointments online, referrals, etc.), the use of patient data and additional services relating to information relevant to patient care (Microsoft 2021b).

IBM

IBM Watson Health Cloud

IBM Watson Health Cloud is part of Watson Health Technology. The health data platform is intended to accelerate regulatory and review processes and is able to support, for example, life sciences companies with their innovation processes (Buisan 2017).

SAP

SAP S/4HANA Cloud

SAP Data Warehouse Cloud

SAP Business Technology Platform

SAP Analytics Cloud

SAP'S open-cloud platform HANA is a service for the development of cloud applications. SAP HANA is a database server with various functions and an in-memory database[62] that can rapidly process large quantities of data. In addition, Online Analytical Processing (OLAP) and Online Transactional Processing (OLTP) boost the system's speed. Using various services, functions and tools, companies are able to develop applications and deploy them or the corresponding data in real time (SAP n.d. b). The SAP S / 4HANA Cloud for patient billing is included in the HANA cloud platform. AI can be used to process and automate payments and cost analyses, for example. With the help of SAP S / 4HANA Cloud tools, improvements can be made to the efficiency of patient management in the treatment context (SAP Deutschland SE & Co. KG April 9, 2019). SAP's revenues from its cloud services grew at the fastest rate in five years in 2021 (tagesschau.de 2021d).

The SAP Data Warehouse Cloud stores a vast amount of data. The application is tailored to companies and IT users and offers immediate access to data via predefined business content and interfaces for the integration of data from a wide variety of sources (SAP n. d. a).

The SAP Business Technology Platform includes a variety of tools, including SAP Integration Suite, SAP Extension Suite and SAP Conversational AI, designed to simplify patient management in the hospital sector. The functions and the data they generate are linked to the cloud platform *HANA* and centrally managed. The SAP Analytics Cloud

62 In-memory databases save data in a main memory, allowing for quicker access (Loos et al. 2011).

is designed to simplify additional steps following patient admission, including monitoring (SAP 2021b).

More detailed information about SAP's bed management solution for the inpatient care sector in selected regions of Germany can be found in section ➔3.3.

SAMSUNG Cloud can be linked to the Samsung Health App and synchronizes all data on all of a users' end devices in real time. The data is protected using Samsung Knox Security[63] (Samsung 2021c).

SAMSUNG
Samsung Cloud

HUAWEI Cloud provides a variety of AI-based services for hospitals and research facilities for epidemic control through its research platform EIHealth. They include viral genome detection, screening methods and AI-assisted CT screening. EIHealth was also used during the COVID-19 pandemic, making its technologies available free of charge to hospitals and research institutions for rapid AI-assisted diagnostics based on CT quantification results, for example (Huawei Cloud 2021b; Huawei Technologies Co., Ltd. April 7, 2020).

HUAWEI
Huawei Cloud
EIHealth

SIEMENS Healthineers Digital Marketplace aims to promote the use and maximize the potential of health data by establishing a "digital health ecosystem" involving healthcare sector stakeholders (Siemens Healthineers 2021h). More specifically, the solution is designed to support "healthcare service providers with the selection, testing, acquisition and operation of digital solutions according to the needs of their institution" by providing access to healthcare applications (Siemens Healthineers 2021q). The Digital Marketplace makes the digital solutions from Siemens Healthineers and its partners available in a curated portfolio (Siemens Healthineers 2021h).

SIEMENS
Siemens Healthineers Digital Marketplace

ALIBABA Cloud offers AI-supported healthcare solutions to address challenges in healthcare provision in China and around the world. In March 2017, the services ET Medical Brain and Doctor You, both intended to support healthcare professionals, were introduced through Alibaba Cloud (➔3.3). In addition, Alibaba Cloud is cooperating with Wuhan Landing Medical-Tech Co. in a cancer research project. The year 2016 saw the introduction of BGI Online, the first comprehensive bioinformatics analysis platform supported by Aliyun (Alibaba Cloud), Intel and the Beijing Genomics Institute (BGI). The platform offers a wide range of services in the field of genome sequencing and other Omics technologies. (Bajpai 2017; BGI 2021). Alibaba Cloud's annual revenues increased year-on-year by 50 % to $ 9.176 million (Business Wire 2021).

ALIBABA
Alibaba Cloud
BGI Online

63 Samsung Knox is an application that functions as an integrated security layer from Samsung, whose tool Samsung Knox Configure can be used for hospital IT. The application is intended to increase the security of company data and simplify device management by IT administrators (Manage Engine 2021; Snyder 2018).

TENCENT
Tencent Cloud

TENCENT Cloud published a COVID-19 platform in April 2020 with the goal of supporting companies, medical facilities and governments around the world in the fight against the pandemic. The cloud-based services include, for example, the facilitation of virtual medical consultations and the provision of reliable and up-to-date health information (Tencent Cloud April 13, 2020).

Tech giants are very active in healthcare cloud computing, as it provides the indispensable basis for the efficient handling of huge volumes of data. Large scales are possible for tech giants thanks to their massive financial resources and corresponding concentration of personnel, skills and technological resources. They are thus able to store exponentially growing amounts of data and process it for a variety of purposes using AI systems.

3.4.2 BLOCKCHAIN TECHNOLOGIES

Blockchain is defined as "a subset of distributed ledger technology (DLT) and constitutes a decentralized database. Entries are combined in a series of blocks that are linked together. A consensus mechanism and cryptography ensure the authenticity and immutability of database entries" (Angerer et al. 2019: 12).

AMAZON
Amazon Web Services
Blockchain-solutions

AMAZON Web Services (AWS) (→3.4.1) has, in cooperation with a public sector player, introduced a blockchain solution for the registration of patients that structures health information with the aim of making it available to healthcare facilities securely and efficiently (Ravanini and Firmiano 2020). AWS is seen as a key player in the blockchain market (Fortune Business Insights 2021).

MICROSOFT
Azure Blockchain Workbench

MICROSOFT recommends that healthcare organizations use its Azure Blockchain Workbench, a solution that can be used in conjunction with the Azure Cloud to develop blockchain prototypes to address the organization's particular needs (Houlding 2018).

IBM
Blockchain-solutions

IBM's blockchain solutions have proven particularly useful during the COVID-19 pandemic, according to the company. IBM offers blockchain solutions for the healthcare and biological sciences sectors, touting their "trust, transparency and data integrity," in addition to other benefits (IBM 2021b). Blockchain services operating in this area should provide a comprehensive overview of patient information and join all system stakeholders in a "supply chain ecosystem" (IBM 2020a). IBM's blockchain solutions can be implemented flexibly and tailored to the specific needs of each company with the help of IBM's blockchain consulting services (IBM 2021c).

SAP's blockchain-based center, called SAP Information Collaboration Hub for Life Sciences, makes it possible to track pharmaceutical products and enables the elimination of returned counterfeit products before they can be reshipped (SAP News Center Jan. 16, 2019).

SAP
SAP Information Collaboration Hub for Life Sciences

SAMSUNG uses blockchain technology for example for decentralized health apps (Health DApps) (Samsung 2021b).

SAMSUNG
Blockchain-solutions

HUAWEI has made the platform Blockchain Service (BCS) available, through which healthcare sector contract templates can be accessed (Huawei Cloud 2021a).

HUAWEI
Blockchain Service

ALIBABA has been cooperating with Chinese authorities since 2017, leading to the implementation of the Ali Health Blockchain, which is an extension of the existing Alibaba Cloud system (Suberg 2017; Forkast.News 2020).

ALIBABA
Ali Health Blockchain

TENCENT announced a partnership in 2019 with Shuidi / Waterdrop (→ 3.4.9). They aim to establish a blockchain-based medical and insurance solution that will be integrated into Tencent's messenger app WeChat. Healthcare facilities and insurance companies are also to benefit from blockchain technology, for example in invoicing or secure data storage (Forkast.News 2020; Suberg 2019).

TENCENT
Blockchain-solutions

PHILIPS' Healthcare division includes the Philips Blockchain Lab, aimed at linking stakeholders from the technology and healthcare sectors for the purpose of researching blockchain solutions for the healthcare industry (Blockchain Healthcare Review 2019).

PHILIPS
Philips Blockchain Lab

INTEL launched the Pandemic Response Technology Initiative (PRTI) in the wake of the COVID-19 pandemic to explore opportunities for blockchain technology. Over 200 projects have since been started, all utilizing Intel technology within the initiative. In partnership with ConsensSys Health, Intel announced in late summer 2021 the development of a privacy-friendly blockchain tool that can be used for research activities. This technology is also being used by the company Leidos in cooperation with the US-American Centers for Disease Control and Prevention (CDC) for a contact-tracing app in the COVID-19 pandemic. The technological foundation includes the Intel Xeon Scalable platform, which in combination with Intel Software Guard Extensions (Intel SGX), is to provide more secure storage (Wayner 2021).

INTEL
Pandemic Response Technology Initiative

Blockchain-solution

Tech giants are primarily deploying blockchain-based technologies for health-related applications in areas where the traceability of data flows is particularly important in terms of the function of the application in question and the security of those from whom the data originates. The market size of blockchain technology in the health sector was $ 281 million in 2020 and is expected to reach $ 6.17 billion by 2027 (Global Market Insights 2020).

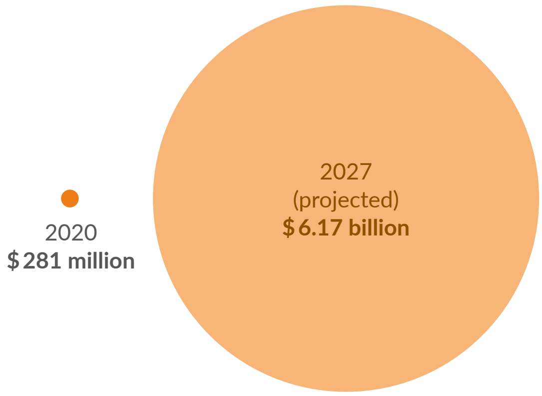


FIGURE 10: **Market size of blockchain technology in healthcare**

Source: Authors. Data: Global Market Insights 2020, Bertelsmann Stiftung

3.4.3 MEDICAL TECHNOLOGY AND BIOTECHNOLOGY

Medical technology focuses on "the use of technical devices for the diagnosis and treatment of diseases" (Information System of the Federal Health Monitoring 2021). A wide range of medical technologies are covered, from pregnancy tests to imaging procedures such as MRIs. Medical technology is relevant for prevention, diagnostics, monitoring, treatment and caregiving (MedTech Europe 2020).

The Organization for Economic Cooperation and Development (OECD) defines biotechnology as "the application of science and technology to living organisms as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services" (OECD 2013: 156).

Technologies that have become widely known, such as ultrasound and X-ray, are just as relevant as comparatively new technologies, like genome analysis and cellular engineering in stem cell research (Wintermantel and Ha 2009). Medical technology and biotechnology procedures are making an ever greater contribution to the advancement of precision medicine, which focuses on predictive, preventive and therapeutic options tailored to individual patients.

PHILIPS has transformed itself since 1990 "from an electronics company to a health coach" (Telgheder 2016) by continuously restructuring the company and reorganizing its areas of business (Kindermann and Lindemann 2018: 39-40; Philips 2021b).[64] Since the spin-off of the lighting segment, the focus has been on the "so-called 'health continuum,' in which professional diagnostics are to be linked with monitoring, diagnostics and household products for a healthy lifestyle (…)" (Kindermann and Lindemann 2018: 48). As early as 2016, the company presented its Connected Personal Health Innovations[65] at the international technology trade fair IFA, highlighting a clear focus on users (ibid.: 55). The tech giant seeks to drive digitalization in the area of medical technology and, as part of that effort, is equipping clinics in Germany and elsewhere with state-of-the-art, networked devices (Philips 2019b, 2019a, 2020a) (➔3.4.9). Through its activities, the company is creating a complete, integrated ecosystem – from technologies for individual users to large-scale medical devices for healthcare facilities. The data volumes generated converge in the company's own platform, called Philips HealthSuite (Philips 2021c) (➔3.2 and ➔3.3).

PHILIPS

Philips Connected Personal Health Innovations

SIEMENS spin-off Siemens Healthineers AG focuses on the development of digital health solutions, medical imaging, laboratory diagnostics and point-of-care testing.[66] The company's goals include pushing forward the digitalization of the healthcare system in general and the development of precision medicine in particular (Siemens Healthineers 2021w, 2021m). Siemens Healthineers Advanced Therapies refers to the implementation of "modern imaging procedures and software applications (…), [which support] the entire course of therapy, from initial diagnosis to treatment planning and support during surgical interventions to aftercare" (Siemens 2021a). The clinical solutions of Advanced Therapies include application areas such as cardiology, neurology, oncology, surgery, infectious diseases and COVID-19 (Siemens Healthineers 2021k). With the acquisition of Corindus Vascular Robotics, Inc., the Advanced Therapies division has been augmented by a "precision robotics platform" (Siemens Healthineers Nov. 4, 2019) (➔3.4.9).

An additional example of digital solutions provided by Siemens Healthineers is Enterprise Imagine IT, which is designed to support work processes and administration in the daily operations of healthcare facilities by way of comprehensive networking (Siemens Healthineers 2021j).
In addition, Siemens Healthineers developed BioMatrix Technology, which adapts to individual anatomic differences of patients in imaging, for example, thereby boosting precision and improving the efficiency of the treatment process (Siemens Healthineers 2021d).

Siemens is also active in medical technology and biotechnology with additional corporate offshoots. Siemens Healthcare Diagnostics Inc. develops clinical diagnostic and therapy services. These include blood gas monitoring and hematology services as well as data management solutions for the prevention, diagnosis and treatment of diseases (Bloomberg 2021). The Siemens Healthcare Laboratory LLC offers biopharmaceutical

SIEMENS

Siemens Healthineers

Advanced Therapies

Enterprise Imaging IT

BioMatrix Technology

Siemens Healthcare Diagnostics Inc.

Siemens Healthcare Laboratory LLC.

64 Medical technology is increasingly becoming a focus of the tech giant's activities. Philips has acquired numerous companies in the field of medical diagnostics and was only still active in three sectors by 2007: Lighting, Consumer Lifestyle and Health. The Health division became the continually growing focus of the company. In 2016, Philips spun off Lighting, its original field of business (Kindermann and Lindemann 2018: 40–48).

65 Included in the offerings are electronic toothbrushes that are able to transmit data to apps (Philips Sonicare FlexCare Platinum Connected toothbrush) and the app-based Philips Heart Health Program, which is designed to help users minimize lifestyle-based risk factors for heart disease (Kindermann and Lindemann 2018: 55; Philips 2017) (➔3.2).

66 Point-of-care testing (POCT) refers to decentralized, laboratory diagnostics. These are laboratory procedures that can be performed in close proximity to the patient (Luppa et al. 2017: 4).

services, such as the development of therapies and diagnostic tests as well as the marketing of the corresponding solutions (Siemens Healthineers 2021p).

APPLE
AliveCor KardiaBand

APPLE AliveCor KardiaBand, the armband that integrates with the Apple Watch (fourth generation or later) and which has been certified and approved by the U.S. Food and Drug Administration (FDA), is able to record an electrocardiogram in addition to displaying heart rhythm and heart rate, providing an alert when the heart rhythm deviates from normal. It has been approved in Europe as a medical device with CE certification (Apple 2020; Krüger-Brand 2020: 378).

INTEL
Hardware and software for medical imaging

INTEL offers a variety of hardware and software components for medical imaging. These include standardized computing platforms designed to simplify imaging. Intel has integrated edge computing into the platforms, allowing for near real-time medical image analysis, which enables more rapid decision-making (Intel Corporation 2021).

SONY
NUCLeUS

SONY's medical technology solutions are expected to provide significant qualitative improvements for minimally invasive and microsurgical imaging procedures through high-definition 3D and 4K technologies (Sony 2021a). Sony's digital imaging platform NUCLeUS is of particular importance to healthcare professionals in this regard (→ 3.2).

In addition to cloud-based data processing, a wide range of medical technology and biotechnology products and services – with differing emphases – also play a significant role for the involvement of tech giants in the healthcare industry. Procedures and products related to imaging, in addition to omics technologies and other laboratory technologies, are currently a focus.

3.4.4
ROBOTICS

Robotics includes the development, production and control of robots (Bendel 2021). Robots can be understood as “sensorimotor machines that have at least three distinct levels of free mobility” (Woopen and Jannes 2019). They can be built to resemble humans or they can take on more abstract forms (ibid.). With advances in the development of artificial intelligence along with software, mechatronic and electronic innovations, robotics will also develop further and increasingly support more health-related application areas. There are, for example, applications within clinical medicine, such as surgery, radiology and molecular medicine, as well as in care and rehabilitation (Stallkamp and Langejürgen 2019: 84; Angerer et al. 2019: 12).

Robotics have become increasingly relevant for the field of nursing in particular, which is partly reflected in the significant number of research projects and new companies active in this area (Stallkamp and Langejürgen 2019; Weichert 2018; van Wynsberghe 2016). Robotics-based solutions fuel hopes that healthcare provision can become more efficient without compromising quality, thus relieving the burden on health workers (Stallkamp and Langejürgen 2019: 99).

AMAZON Web Services (AWS) has developed an open-source hospital simulation, with which companies in the healthcare sector can run robotic simulations. The simulation was tested, for example, using a PR2 robot developed by Willow Garage[67] (Hansen 2020).

AMAZON
Amazon Web Services
Robotic simulation

META (formerly Facebook) announced in November 2021 that its research department FAIR (➔3.5) has developed tactile technologies that provide robots with a sense of touch. One of those is ReSkin, a robot “skin” made up of sensors and wearables that were developed in cooperation with Carnegie Mellon University. According to FAIR, ReSkin is a source of extensive contact data that can serve AI advancement in the area of “touch-based tasks” and can support healthcare provision, particularly in tasks that require greater sensitivity (Tarantola 2021).

META
(formerly Facebook)
Tactile Technologies
ReSkin

SIEMENS Healthineers has made CorPath GRX available, a robotics-based system for radiological and cardiological procedures (Siemens Healthineers 2021e; Corindus 2020; Siemens Healthineers 2021o). With the acquisition of the technology company Corindus Vascular Robotics, Inc., one of the world’s leading specialized companies for robotic systems, Siemens Healthineers is pursuing the vision of “performing minimally invasive procedures more precisely, faster and more effectively” (Siemens Healthineers Aug. 8, 2019) (➔3.4.9).

SIEMENS
Siemens Healthineers
CorPath GRX

67 Willow Garage, Inc. is a company that develops hardware and open-source software for robotics technologies. PR2 is a research and development platform created by Willow Garage for robotic systems (Vizologi 2021).

PHILIPS
Robotics-assisted care

PHILIPS has signaled its intention to increase its activities in robotics-assisted care with the appointment of a new robotics executive (Mageit 2021).

IBM
Robotic Process Automation

IBM relies on Robotic Process Automation (RPA), an automation technology designed to complete administrative tasks such as filling out forms. With RPA, APIs and user-interface interactions are linked, allowing human processes in the completion of tasks to be imitated and performed automatically. According to the company, the increased automation will make processes more efficient, optimize data entry and save time and money in addition to promoting more rapid decision-making (Williams 2021).

INTEL
Robotic solutions

INTEL offers a variety of technologies which can be used for the development and deployment of robotics in the healthcare sector. They include applications in surgical assistance and service robots. According to Intel, six different technologies provide solutions for robotics in healthcare both to hardware manufacturers and to software providers (Intel 2021).

MICROSOFT
Versius
Silica

MICROSOFT and CMR Surgical announced in May 2021 that they were working together on the next generation of CMR Surgical's robotics-supported surgery system Versius. In Microsoft's project Silica, developed as part of the Microsoft Cloud, clinically anonymized data from surgical procedures were collected and analyzed on a miniature storage device that is capable of storing this data for tens of thousands of years (CMR Surgical 2021b, 2021a).

NVIDIA
NVIDIA Jetson AGX Systems

NVIDIA's deep learning technology NVIDIA Jetson AGX Systems can be used, according to the company, for embedded robotics in various fields, including healthcare (NVIDIA 2021f).

SAMSUNG
Ballie

SAMSUNG presented Ballie in 2020, a personal robot designed to assist the elderly with the help of AI. With its sensors and cameras, the small, spherical robot can communicate with other end devices in the household environment and, according to the company, meet the needs of its user (Landi 2020).

SAP
Intelligent Robotic Process Automation

SAP's technology Intelligent Robotic Process Automation, which is integrated into SAP's Cloud, is used by Zuellig Pharma. The technology allows for the digitalization and automatization of manual processes (Andree 2020).

SONY has developed, in cooperation with Harvard University, a miniature operations robot (Mini-RCM), which was inspired by origami: It is built up in layers and cut by laser to allow for flexible directional movement. The robot is primarily intended for use in surgery requiring delicate skills. It has not yet been deployed in real-world operational settings (Holt 2020).

SONY
Mini-RCM

When it comes to products and services of robotics for the current healthcare industry, tech giants do not (yet) play a role that is comparable to their significance in healthcare cloud computing. Their products are primarily used in the areas of surgery, imaging, care and service.

3.4.5 SERVICE PROVISION STRUCTURES

The activities of tech giants focused on establishing structures for primary care / service provision within a specific and nationally regulated healthcare system are currently limited to the United States and China. The focus of such efforts is on the interlinking of technologies, health-related services, healthcare facilities and various stakeholders in the healthcare provision industry. One example is telemedicine care facilities in the United States.[68]

APPLE began building healthcare facilities in 2018. Initially, the tech giant began providing care to employees and their families at two clinics it opened in California's Santa Clara County, but a group of such clinics is planned (Armbruster et al. 2018). Apple has declined to provide much information to the public regarding its so-called AC Wellness clinics. The website, however, indicates that AC Wellness is convinced of its ability to deliver high-quality healthcare and a unique experience to its patients. "We believe that having trusting, accessible relationships with our patients, enabled by technology, promotes high-quality care and a unique patient experience," the site states (AC Wellness 2020). In addition, Business Insider has reported that Apple is currently developing an app called HealthHabit, which is also only available inside the company and is designed to connect its employees with AC Wellness (Jercich 2021). Apple has touted the service by saying that close connectivity between patients and healthcare professionals is provided by various technologies and apps, both in a treatment setting (e.g., hospital) and from home. At the same time, the open-source approaches of these technologies are expected to facilitate medical research (Apple 2021a).

APPLE
AC Wellness

68 It is estimated that more than 25 % of all medical consultations in the United States already take place via telemedicine channels (Flumignan et al. 2019).

AMAZON
Amazon Care

AMAZON offers its employees and their families virtual and in-person healthcare through Amazon Care (Amazon March 17, 2021), described as "a kind of virtual doctor's office" (Mirza 2020). As part of virtual care, a variety of digital channels relating to healthcare provision are offered, all of which are based on the Amazon Care app. Care Chat and Video Care are the two telemedicine applications that facilitate virtual patient interaction with medical professionals (Amazon Care 2021). Through Amazon Care, patients are able to book appointments and they receive summaries of their diagnoses and the treatments discussed. With "in-person care," Amazon Care offers personal consultations with healthcare professionals and drug deliveries in select cities and regions (Amazon March 17, 2021). Both telemedicine consultations and in-person care is provided by Care Medical, which is exclusive to Amazon (Dodge 2021). Amazon Care launched in 2019 for employees in the greater Seattle region and was expanded in September 2020 to the entire state of Washington (Rathenow 2020). In early 2021, the company announced it would be making Amazon Care available to employees in all 50 U.S. states and also to other companies (Amazon March 17, 2021).

TENCENT
Tencent Trusted Doctors

TENCENT Doctorwork established the first clinic of its own in Beijing in 2018: the Tencent Doctorwork Clinics (Finch 2018). As a product of the merger of Tencent Doctorwork with the startup Trusted Doctors, there are now 50 clinics belonging to the newly named Tencent Trusted Doctors (Tuna 2019a). Through its proprietary app WeChat, the company integrates 38,000 accounts of health-care providers and offers 24,000 health-related and wellness-based mini programs. With the implementation of the WeDoctor app, Tencent has also made it possible to set up appointments online for consultations with 290,000 doctors and 2,700 hospitals (Choueiri et al. 2020: 5-6).

In individual cases, tech giants are building structures for the provision of health services that could in principle be expanded in the future. Initially, the focus has primarily been on hospitals and on networked and thus cross-sector healthcare provision association with hospitals, mostly for the company's own employees.

3.4.6
HEALTH INSURANCE

Only very few tech giants offer their own health insurance. Currently, there is Oscar Health in the United States and WeSure in China. The U.S. insurance company Haven Healthcare[69] was dissolved at the end of February 2021, according to media reports (Toussaint 2021; Son 2021).

GOOGLE / ALPHABET
Oscar Health

ALPHABET finances Oscar Health, a U.S. health insurance company. It offers telemedicine services, based on a technology platform and the digital profiles of the insured (Oscar Health 2021; Heimlich 2021).

TENCENT
WeSure

TENCENT's app WeChat owns the integrated platform WeChat Intelligent Healthcare, which has, since 2017, included the service WeSure, along with other applications (Meskó et al. 2020: 61-62). WeSure is a platform for the purchase of all types of long-term insurance policies. It already has 50 million customers and a total of 100 million registered users (Digital Finance 2020). The company works with the 20 largest Chinese (including PICC, Ping and Taikang Insurance and others) and foreign insurance companies (including AXA Insurance and others) (WeSure Dec. 18, 2019; Digital Finance 2020). WeSure creates risk calculations that are generated from the existing profiles and insurance policies[70] of WeChat users (Digital Finance 2020).

Tech giants (so far) only offer health-related insurance policies sporadically. As with technologies for patients and users, it can be seen here too that Chinese offerings extend well beyond the health sector.

69 Haven Healthcare, a joint venture established in 2018 between Amazon, JPMorgan Chase – the largest bank in the United States – and Berkshire Hathaway – Warren Buffet's holding company – wanted to "offer solutions to sink healthcare costs and to make the complex system of hospitals, physicians pharmacies, insurers and pharmaceutical companies more transparent and cheaper" (Werner 2018). To do so, Haven Healthcare created a health insurance program for the 1.2 million U.S.-based employees of the three companies, thus circumventing insurance contracts with third parties (Meskó et al. 2020: 33-34; Juul 2019). In mid-2021, it was announced that JPMorgan Chase would keep Haven going without Amazon, but with other healthcare organizations (Ennis and Pifer 2021).

70 Initially, WeSure offered smaller add-on policies for smartphones and other electronic devices that collected data necessary for risk assessment (Digital Finance 2020).

3.4.7
PHARMACEUTICALS SUPPLY

Tech giants are increasingly active in the area of pharmaceuticals delivery. First and foremost, they cooperate with established pharmaceuticals companies and acquiring startups (→3.4.9), but they have also started to produce their own medicines and are becoming increasingly active in drug distribution.

AMAZON

Amazon Basic Care

Amazon Pharmacy

AMAZON is concentrating its efforts in the pharmaceutical sector on the sale and distribution of over-the-counter and prescription pharmaceuticals (Meskó et al. 2020: 34; Köbe 2020).[71] Although over-the-counter (OTC) medicines have long been part of Amazon's offerings in the United States,[72] the company introduced its first over-the-counter line in the U.S. market in 2017 (Borsch 2018; Meskó et al. 2020: 34). The Amazon Basic Care line of products includes 60 over-the-counter medications, including pain relievers, anti-allergy medicine and hair-growth remedies, produced by Perrigo (Borsch 2018). Basic Care is linked with Health Navigator, which allows users to, for example, enter symptoms to access Basic Care products (Alashe 2019).

In 2018, Amazon acquired the online pharmacy PillPack (Farr 2019b). At the time of the acquisition, Pillpack already possessed pharmacy licenses in all 50 U.S. states. The acquisition makes it possible for Amazon to integrate existing infrastructure and know-how (Ballentine and Thomas 2018; Werner 2018). Patients can receive their medications on an as-needed basis, pre-packed and pre-sorted – and they are no longer reliant on healthcare professionals for the correct dosage (Barton and Brandt 2018).[73] The acquisition of Pillpack was accompanied by the launch of Amazon Pharmacy (Blasius 2020). Doctors can send prescriptions directly to the mail-order pharmacy, with the patient's linked Amazon account then used to trigger delivery of the medication – with the company supplying its Prime customers free of charge (Blasius 2020; Egert 2020; Schersch 2020).

Initially, the offering was limited to the U.S. market, but the Amazon Pharmacy trademark has also been registered in Canada, the United Kingdom and Australia (Meskó et al. 2020: 35). In August 2020, Amazon Pharmacy was also registered as a European Union trademark and included in the European Business Register (Rohrer 2020; Blasius 2020). An expansion of the service to the German market seems likely since Amazon has more customers here than in any other EU member state. The introduction of the e-prescriptions, planned for January 2022, will be particularly helpful to the company (Egert 2020; Federal Ministry of Health 2021b).

71 Amazon has been in possession of wholesale drug licenses in at least 12 U.S. states since 2017 (Meskó et al. 2020: 34).

72 In the United States, distributors are allowed to sell over-the-counter medicine, which is not possible in Germany (Borsch 2018).

73 The service is primarily targeted at patients with chronic conditions who must take a variety of medications on a regular basis. In addition to dosage information, the packages of medication also include precise instructions on administration (Barton and Brandt 2018).

SAMSUNG has established itself in the pharmaceuticals sector with the founding of two spin-offs. One of those is Samsung Biologics, which has been producing biopharmaceuticals since 2011 (Samsung Biologics 2020a), and the other is Samsung Bioepis Co. Ltd., which was founded in 2012 and produces biosimilars (Samsung Bioepis 2020).[74] Samsung is hoping to secure a 30 % market share in the biopharmaceuticals industry by 2023 (Inside IT 2021).

SAMSUNG
Samsung Biologics
Samsung Bioepis Co. Ltd.

ALIBABA has integrated the Tmall Online Pharmacy into its platform Alibaba Health to provide users with a large selection of pharmaceutical and health-related products, such as over-the-counter medications and health-related devices (alizila 2015).

ALIBABA
Tmall Online Pharmacy

Tech giants are increasingly active in different areas of pharmaceuticals supply. Their products and services are primarily focused on distribution and logistics, particularly of over-the-counter drugs, but also on production. Amazon has already established an online pharmacy in the U.S. Samsung is the only tech giant thus far that is seeking to become a player in the pharmaceuticals industry through its two spin-offs (Samsung Biologics and Samsung Bioepis).

3.4.8 MOBILITY AND LOGISTICS

Individual tech giants have taken initial steps to enter the mobility and logistics sector.

GOOGLE's Wing drone project, which was launched by Google's "X" division, became an Alphabet subsidiary in 2018. The firm's all-electric drones transported first aid kits, water and food during their first official delivery flights, which were conducted in Australia (Hemmerdinger 2020). The drones were also deployed to deliver items like medicine and prescription drugs in the U.S. state of Virginia during mandated COVID-19 lockdowns (Block 2020). In the United States, drone deliveries are subject to strict Federal Aviation Administration (FAA) rules. In order to become licensed, projects like Wing participate in the FAA Unmanned Aircraft Systems Integration Pilot Program (Bradbury 2020).[75]

GOOGLE / ALPHABET
Wing

74 "Biosimilars are copycat versions of biopharmaceuticals, that is, biotechnologically produced drugs" (VfA 2019).

75 Amazon has also been licensed to use drones for future package deliveries in the context of its Amazon Prime Air service (Bradbury 2020).

AMAZON

Amazon Prime Air

AMAZON Prime Air is partnering with Amazon Pharmacy to transform the airplane, logistics and pharmaceutical industries by adding drone delivery services to the drug shipping market. A new technology will also allow prescription drugs to be delivered by drone (Goulding 2020).

According to the Wall Street Joural, Amazon already sells medical supplies and aims to become a major supplier to hospitals and medical facilities across the United States (Paavola 2018).

A few of the tech giants have begun to enter the mobility and logistics sector, focusing primarily on drone projects.

3.4.9 HEALTHCARE MARKET

Tech giants are tapping into the healthcare market through a variety of activities. Partnerships and collaborations, as well as joint projects and programs, play an important role here. In addition to acquiring other companies, tech giants are also investing strategically in various startups and their own spin-off projects. These activities allow them to gain significant market access and acquire the expertise they need to successfully expand into the healthcare market (Kindermann and Lindemann 2018: 54). A growing number of increasingly diverse cooperations are anticipated among the various established healthcare actors and tech giants, a development that will prove instrumental in shaping the future of healthcare and healthcare delivery (see, among others, Krüger-Brand 2020; Choueiri et al. 2020; Choueiri et al. 2019; Juul 2019; Hahn and Schreiber 2018). The experts interviewed for this study share this assumption.

PARTNERSHIPS, PROGRAMS AND PROJECTS

By working in partnership with others on projects, initiatives and programs and thereby pooling their knowledge, expertise and resources, stakeholders such as companies or academic institutions can achieve more in addressing complex issues than they might on their own. Public-private partnerships (PPP), that is, cooperative agreements between two or more private-sector and public-sector parties, are seen as particularly promising options in this regard. PPPs can include, for example, partnerships between private and public hospitals, outpatient care providers, pharmaceutical and medical technology companies, IT companies and non-governmental organizations (NGOs). The forms they take can vary from project-specific collaborations to long-term strategic alliances to complex multistakeholder consortia (Ballantyne and Stewart 2019: 316-317; Yildirim et al. 2016: 3-5).

GOOGLE / ALPHABET conduct a variety of collaborations and projects with several companies, research centers and institutions in the healthcare sector.

UK National Health Service (UK NHS) – Google DeepMind Partnership
Google's activities in healthcare are driven by DeepMind Health, among others. Google's acquisition of DeepMind has enabled the company to process and apply big data for use in developing its AI-driven systems and applications. For example, Google DeepMind collaborated with the UK National Health Service (UK NHS) to develop an app for kidney diseases (Ballantyne and Stewart 2019: 321; Hawkes 2016). As part of the partnership, the NHS supplied the tech giant with a total of 1.6 million fully complete patient records in 2015. This included personal data that had been stored with NHS, which contained sensitive information regarding abortions, drug abuse and a person's HIV status, for example. Google DeepMind used this data for the Streams app, which is used in the context of kidney conditions (➔3.3).

The fact that this data was shared became a subject of public controversy, especially since the company had not obtained the informed consent of insurance holders to share the data (Ballantyne and Stewart 2019: 321; Hern 2017). In 2019, the Streams app and the DeepMind Health team were incorporated into the Google Health division. This move prompted further controversy, as DeepMind had provided assurances at the outset of its collaboration with the NHS that the health data it received would not be linked to Google products or services (King 2019; Hern 2018).

Project Nightingale: Ascension-Google Partnership
Since 2018, Google has partnered with Ascension, a major U.S. healthcare service provider featuring 150 clinics and several outpatient healthare facilities, on Project Nightingale (Hurtz 2019). According to the Wall Street Journal, the project allows Google access to a massive set of health-related data that includes lab data, treatment data and hospital records from millions of U.S. patients across 21 states (Copeland 2019). The joint project is highly controversial, as neither doctors nor patients have been informed that health data will be shared and stored within Google Cloud. Google and Ascension, on the other hand, claim that their actions are compliant with privacy and security regulations as stipulated by the U.S. Health Insurance Portability and Accountability Act (HIPAA), which allows data to be shared as long as it is used to improve care (Hurtz 2019).

Alliances with pharmaceutical companies
Google's spin-off Verily Life Sciences, LLC (Verliy) maintains long-term strategic alliances with pharmaceutical companies such as Otsuka, Novartis, Pfizer and Sanofi in order to advance drug research and development (Farr 2019a) (➔3.5).

Google Cloud partnerships and alliances
Google Cloud has maintained a partnership with the U.S.-based Mayo Clinic since 2019. As part of the partnership, the clinic uses the Google Cloud Healthcare API to improve data capabilities and interoperability (Meskó et al. 2020: 11).

Another cooperation, namely that between Google Cloud and the Broad Institute of Harvard and MIT, enables the connection of Cloud Life Sciences infrastructure with the research institution's genome analysis tools (Meskó et al. 2020: 12). Together with these and other healthcare companies, research centers and healthcare providers, such as the Brigham Research Institute at Brigham and Women's Hospital (BWH), the Ontario Institute for Cancer Research and the Wellcome Trust Sanger Institute / European Bioinformatics Institute, Google Cloud forms the Global Alliance for Genomics and Health. This alliance is dedicated to developing common approaches for the secure and effective sharing of genomic and clinical data within the cloud (Meskó et al. 2020: 12; Writer 2014).

GOOGLE / ALPHABET
UK NHS – Google DeepMind Partnership
Project Nightingale
Alliances with pharmaceutical companies
Google Cloud partnerships and alliances
Further exemplary partnerships

Other exemplary partnerships
Google leads a partnership with Mount Sinai Hospital in New York City that involves using the platform Google Nest in COVID-19 hospital wards to electronically record the health status of patients and collect data on the illness (Meskó et al. 2020: 17).

Verily Life Sciences, LLC (Verily), is leading partnerships with Stanford and Duke universities on a longitudinal study, Project Baseline (Meskó et al. 2020: 11; Krüger-Brand 2020: 376) (➔3.5).

Together with GlaxoSmithKline[76] (GSK), Verily founded the startup Galvani Bioelectronics to research bioelectric microimplants (Donner 2020).

Google for Startups Accelerator is a three-month program designed to support startups in a variety of areas including health, wellness and fitness through measures like workshops, mentoring and strategic support (Frank 2021).

Google is also an entrepreneurial founding partner of Singularity University, a globally connected learning and innovation community that seeks to foster startups and networks in AI, robotics and digital biology and medicine through executive education, high-profile conferences, innovation consulting, and other programs (Singularity Group n. d. a, n. d. b).

APPLE

Partnerships with universities and research institutions

Partnership on AI

Partnership with IBM

APPLE maintains numerous research projects with various partners that include universities and research and healthcare institutions (➔3.5).

The Partnership on AI (PAI) is an organization seeking to communicate the opportunities provided by AI and its potential in the context of, among other things, public health, sustainability and education. PAI is backed by tech giants such as Apple, Meta (formerly Facebook), Google, DeepMind, Amazon, IBM, Samsung and Microsoft, as well as NGOs and humanitarian organizations. In addition to bringing expertise on the subject of AI to the broader public, PAI aims to inform the public of the risks and security issues involved with the use of AI (PAI 2021a, 2021b).[77]

Since 2014, Apple and IBM have been working together to deliver AI-based enterprise solutions and cloud-based services by leveraging the synergies of Apple's ML and IBM Watson (IBM 2020c; Apple July 15, 2014).

META (formerly Facebook)

Oculus Quest

fastMRI

Chan Zuckerberg Initiative, LLC.

META's (formerly Facebook) partnership with Children's Hospital Los Angeles (CHLA) regarding the Oculus Quest virtual reality goggles is discussed in section ➔3.3.

Comments on the Facebook AI Research (FAIR) and New York University (NYU) Langone Health partnership regarding fastMRI, and comments on the Chan Zuckerberg Initiative, LLC, (CZI) can be found in section ➔3.5.

76 As a U.K.-based pharmaceutical company, GlaxoSmithKline (GSK) focuses on the development and production of vaccines, medicines and general health products for consumers (GSK 2021a, 2021b).

77 However, media reports highlight that NGOs in particular are not satisfied with the organization's communication of critical aspects (Johnson 2020).

AMAZON cooperates with Care Medical in providing the telehealth service Amazon Care (➔3.4.5). As part of Haven Healthcare, Amazon entered into a joint venture with JPMorgan Chase and Berkshire Hathaway in 2018 which, according to media reports, was dissolved at the end of February 2021 (Son 2021; Toussaint 2021) (➔3.4.6).

The cloud-based Amazon Web Services (AWS) solution, including Amazon Neptune Technology, is used by partners such as Illumina for genome sequencing and data storage (Meskó et al. 2020: 36). Partners are also developing their own applications on the basis of AWS, such as the U.S. Cleveland Clinic's clinical neurology app (Meskó et al. 2020: 36). AWS is launching a first-of-its-kind support program for healthcare startups in 2021 that includes ten selected companies. Some of the items in development by the startups include voice assistants, virtual reality (VR) technologies, and remote monitoring programs. Amazon supports the program's startups with financial resources, expertise and its brand, said Ulrike Deetjen, a partner at management consulting firm McKinsey (Rybicki 2021).

Amazon's Alexa
There are a large number of partnerships and projects associated with Amazon's AI-powered voice assistant Alexa (➔3.2).

A COVID-19 tool developed by the U.S. Mayo Clinic is being implemented with Amazon Echo and Amazon Echo Dot devices to help patients with handling and preventing coronavirus symptoms (Meskó et al. 2020: 38).

For details regarding Amazon's collaborations with the UK National Health Service (UK NHS), Boston Children's Hospital, Ada Health, Merck & Co., Inc., Techniker Krankenkasse (TK), and KidsMD and the Smart Hospital Room Pilot Project with Los Angeles' Cedars-Sinai Health Center, see sections ➔3.2 and ➔3.3, respectively.

AMAZON
Care Medical
Partnerships with Amazon Web Services, i. a. Illumina, Cleveland Clinic
AWS support program
Partnerships and projecs associated with Alexa and Amazon Echo
Collaborations with the UK NHS, clinics and pharmaceutical companies
KidsMD
Smart Hospital Room Pilot Project

MICROSOFT HoloLens is already being used in a collaboration with U.S.-based Case Western Reserve University and the Cleveland Clinic as part of the Health Education Campus. By providing a holographic simulation of human body parts from different perspectives, HoloLens replaces the use of human cadavers in medical school anatomy courses (Snyder 2019) (➔3.3).

Further partnerships with other organizations such as CAE Healthcare and Medivis are developing software programs for HoloLens that are of benefit to surgeons in planning procedures before an operation and which prove helpful during operations (Meskó et al. 2020: 29).

In 2019, Microsoft developed in partnership with the University of Washington the first-ever automated system (among other things) for data storage on artificial DNA at the Molecular Information Systems Laboratory (Ceze et al. 2019; Woopen et al. 2020).

Microsoft's AI and cloud partnerships

Microsoft Healthcare NExT
Healthcare NExT (New Experiences and Technologies) is an initiative launched in 2017 that is aimed at a profound transformation of healthcare through the use of AI and cloud-based technologies. This goal is to be achieved by combining research, AI and the pooled expertise of the initiative's partners. To unlock new opportunities for AI applications in healthcare, the initiative is investing in resources such as the Microsoft AI in Health Partner Alliance, whose members receive training, access to Micro-

MICROSOFT
HoloLens, i. a.:
Case Western Reserve University
Cleveland Clinic
CAE Healthcare
Medivis
Molecular Information Systems Laboratory mit University Washington
Microsoft Healthcare NExT

Microsoft AI for Health, i. a.:

Novartis AI Innovation Lab

PATH

IRIS

Cascadia Data Discovery Initiative

Further partnerships associated to Microsoft AI, Microsoft Cloud and Microsoft Genomics with universities, clinics and health companies

Project EmpowerMD

Hospital Exam Room of the Future

Partnerships with Microsoft Azure and Microsoft (Azure) Health Bot Service

soft's technologies, expertise and data (Microsoft Feb. 16, 2017).

Microsoft AI for Health

Microsoft AI for Health is a five-year program within the Microsoft AI for Good initiative (➔3.1) that is designed to provide research institutions with access to resources, technologies and expertise in addressing global health challenges. This involves, for example, a $40 million investment in AI research in healthcare. The program focuses on (1) research on the prevention, diagnosis and treatment of diseases; (2) protecting against global health crises; (3) reducing inequalities in access to healthcare (Microsoft Switzerland Jan. 30, 2020a; Microsoft 2020).

The Novartis Foundation is part of the AI for Health program, which combines the former's pharmaceutical expertise with Microsoft's AI and data management knowledge. Established for this purpose, the Novartis AI Innovation Lab aims to help shorten the amount of time needed for the research and development of drugs, while reaching more patients faster and reducing costs (Evans 2020). The Data42 platform, which uses AI to generate insights from clinical trial data, is used to support these goals (Novartis Switzerland 2021).[78] One example involves Microsoft and the Novartis Foundation partnering to develop AI-enabled health technology in creating an intelligent image atlas for use in detecting leprosy. By enabling the early detection of the disease, the goal here is to help prevent nerve damage among affected patients (Novartis Foundation July 29, 2020; Microsoft Switzerland Jan. 30, 2020b).

Another AI for Health partnership involving the Integrative Brain Research Institute at Seattle Children's Hospital and Veritas Genetics entails developing a database of genetic and phenotypic data for infant mortality and Sudden Infant Death Syndrome (SIDS) research[79] with Microsoft Genomics and Microsoft Azure (Microsoft Switzerland Jan. 30, 2020a; Bangur 2019).

PATH (Program for Appropriate Technology in Health) is a non-profit organization (NPO) funded by AI for Health that operates in more than 70 countries. PATH aims to leverage AI in improving access to healthcare and in developing strategies for disease diagnostics and treatment (PATH 2021, Jan. 29, 2020).

IRIS (Intelligent Retinal Imaging Systems) is also part of the AI for Health initiative. IRIS provides cloud-based diagnostic imaging technology for diabetic retinopathy applications (IRIS 2020, 2017).

The Cascadia Data Discovery Initiative (CDDI), as part of AI for Health, is a collaboration of the Fred Hutchinson Cancer Research Center, BC Cancer, the University of British Columbia, the University of Washington eScience Institute, and the Knight Cancer Institute at Oregon Health & Science University. The CDDI focuses on enabling biomedical data-sharing in a robust data ecosystem. It thereby aims to facilitate data-driven research while fostering and expediting the exchange of information between the initiative's participating institutions (Fred Hutchinson 2021a; Fred Hutchinson News Service Jan. 29, 2021).

78 Novartis uses clinical trial data collected and stored over the past 20 years for this purpose, which includes approximately 20 petabytes of data from 2,700 individual Novartis studies. While Novartis has thus far been able to collect and merge the data, it has not yet been able to sufficiently analyze it. This data could prove significant particularly with regard to efforts to examine correlations between diseases and medications (Novartis Switzerland 2021; Mijuk 2020).

79 Data from the U.S. Centers for Disease Control and Prevention (CDC) on this issue, which already includes 26 million births and deaths, was used to start with. This data was then supplemented with additional U.S. datasets covering a total birth period of six years, which allowed for the identification of various correlations, including an increased likelihood of SIDS associated with the smoking behavior of pregnant women (Lee 2019).

AI for Health also supports international scientists conducting research on COVID-19 by providing financial resources, scientific expertise, and AI and cloud computing-related resources (Meskó et al. 2020: 31).

Other Microsoft AI and cloud partnerships
Microsoft engages in other AI-related partnerships, such as that with the University of California, Los Angeles (UCLA Health) aimed at developing predictive algorithms aimed at disease prognosis (Meskó et al. 2020: 27).

Microsoft Azure is also used in the context of various partnerships involving monitoring applications for chronically ill patients. Examples include those with Finland's Helsinki University Hospital, the U.S. telemedicine company Hope Care, and the Portuguese Cova da Beira Hospital Center (Meskó et al. 2020: 30).

Microsoft Azure helps empower a number of institutions such as UCLA Health through its platform that allows users to store and manage clinical and research data. The platform thus helps accelerate clinical research and the delivery of patient care (UCLA Health May 30, 2019).

At Project EmpowerMD, Microsoft conducts research with the University of Pittsburgh Medical Center (UPMC) on an AI-driven system designed to assist medical staff that was implemented in 2019 in a collaboration with Nuance Communications Inc. at the Hospital Exam Room of the Future (Meskó et al. 2020: 26; Microsoft News Center Oct. 17, 2019) (➔3.3).

In 2019, Microsoft began collaborating with SilverCloud Health, the provider of a digital platform that offers mental health services. Microsoft's AI-driven technologies will be combined with SilverCloud Health's expertise to deliver personalized mental health care, including early detection and treatment interventions (SilverCloud Health Oct. 2, 2019).

Microsoft's (Azure) Health Bot Service, which allows for the creation of AI-based virtual assistants (➔3.3), is being developed and applied in collaborations with healthcare organizations such as Premera Blue Cross and Quest Diagnostics (Roach 2019).

Microsoft Azure is engaged in another partnership with software company Epic aimed at creating cloud-based solutions in healthcare (Meskó et al. 2020: 28).

Microsoft Genomics is used in a collaboration with the Klein Lab at the Ichan School of Medicine at Mount Sinai to analyze large genomic datasets and archive the files (Microsoft Customer Stories 2018).

At St. Jude Children's Research Hospital, Microsoft Genomics has been used in pediatric cancer research and in building the St. Jude Cloud platform, which provides genomic data in pediatric oncology (Meskó et al. 2020: 28; St. Jude Cloud 2021).

For details on Microsoft's partnerships with the pharmaceutical company Shire and the NGO EURORDIS, see section ➔3.5.

IBM maintains numerous partnerships in the context of its Watson AI-driven supercomputing project. Watson Health collaborates with companies and institutions to improve clinical decision-making processes by reducing diagnostic errors, optimizing therapies and making personalized medicine possible (Meskó et al. 2020: 40).

An alliance with Apple, Johnson & Johnson and Medtronic is creating large fitness, nutrition and vital-sign datasets from Apple iPhone and iPad users. Pharmaceutical company Johnson & Johnson and medical technology company Medtronic also provide health-related data that will be analyzed by Watson Health to develop personalized health offerings, such as health apps for patients (Dow Jones & Company April 14, 2015).

IBM

Partnerships associated with IBM Watson with companies, universities and research institutions i. a.:

Mayo Clinic

Quest Diagnostics

Alliances with Apple, Johnson & Johnson and Medtronic

IBM is partnering with a handful of healthcare facilities, research labs and universities to test its technologies (IBM Hybrid Cloud and IBM Watson) in the real world. The U.S. Mayo Clinic is just one such institution (IBM 2020d; Streed 2020).

In 2016, Watson Health partnered with Quest Diagnostics to launch the Watson for Genomics application, which features algorithms designed to interpret publication data and draw on genetics in determining individualized treatment options. The application is available in numerous clinics in the United States. At the Portuguese Germano de Sousa Group, Watson for Genomics is applied to accelerate the interpretation of genomic analyses. In 2019, the Swiss university hospital Hôpitaux Universitaires Genève (HUG) began implementing the application in its medical decision-making processes based on individual genetics (Meskó et al. 2020: 41-42).

For details on IBM's partnership with Graticule, see section →3.5.

INTEL's cooperation with the Broad Institute of Harvard focuses on genomics research (Intel Corporation 2020a).

During the COVID-19 pandemic, Intel has also worked with the Medical Informatics Corporation (MIC) in supporting the Sickbay platform to help coordinate ICU bed capacities (Meskó et al. 2020: 57).

INTEL

Broad Institute of Harvard

Medical Informatics Corporation

General Electric Healthcare

Partnerships with companies and universities

INTEL is also partnering with General Electric (GE) Healthcare to advance AI-based medical imaging technology (Intel Corporation 2020b).

The company also partners with ConsensSys and Leido in the area of blockchain technology (Wayner 2021) (→3.4.2).

For information on Intel's partnerships with the University of California, San Francisco (UCSF), and the University of Pennsylvania, see section →3.1.

For details on Intel's partnerships with Dell Technologies and Translational Genomics (TGen), please refer to section →3.5.

NVIDIA maintains partnerships with numerous institutions that use NVIDIA Clara in their research projects, including Johns Hopkins University and King's College London (Meskó et al. 2020: 45) (➔3.5).

The NVIDIA Inception program funds health-related AI and deep learning-focused startups such as Qure.ai and Infervision, among others (NVIDIA 2021a; Meskó et al. 2020: 46) (➔3.5). NVIDIA also collaborates with many startups focused on COVID 19 research by providing them NVIDIA Clara technologies (Meskó et al. 2020: 46-47) (➔3.5).

NVIDIA is part of the U.S. government-led COVID-19 High Performance Computing (HPC) Consortium, which aims to support COVID-19 research by fostering collaboration among leading academic institutions and the private sector. Other members include IBM, Amazon Web Services (AWS), Google Cloud, Microsoft, and Intel (Covid-19 HPC Consortium 2021; Meskó et al. 2020: 46).

In the context of its Deep Learning Institute, NVIDIA partners with Tencent and other firms. One goal of its partnership with the Chinese multinational is to provide developers and researchers training in AI and the opportunity to deepen their technical expertise. Another is to integrate NVIDIA's graphics processing units (GPU) into Tencent's cloud. The two tech giants also plan to work together in developing new training capabilities in AI research (Estes 2017; NVIDIA 2021e).

For details on NVIDIA's partnership with Recursion, see section ➔3.5.

NVIDIA

NVIDIA Clara, i. a.:

John Hopkins University

King's College London

NVIDIA Inception Program

Partnerships with start-ups associated to Covid-19 research

Covid-19 High Performance Computing Consortium

Deep Learning Institute

PHILIPS is collaborating with the University Medical Center Utrecht (UMCU) by using the tech giants' technologies to monitor COVID-19 patients remotely (Philips 2020b). Partnering with the Rostock University Medical Center in the pilot project HerzEffektMV,[80] Philips aims to help improve care for patients with heart conditions by providing the center with hardware and the apps required (Kindermann and Lindemann 2018: 55).

The Health Innovation Port (HIP) enables startups to collaborate with established actors in the healthcare sector. By providing the infrastructure and networks needed to form partnerships, the initiative aims to incubate the co-development of ideas and new business models. German health insurance provider Techniker Krankenkasse (TK) and the German hospital chain Asklepios Kliniken are just two of the Port's participating organizations (HIP 2018).

Philips has been equipping cooperating clinics with the latest technologies, such as ultrasound and X-ray equipment, since 2018. In Germany, Philips has recently entered into long-term strategic partnerships with municipal hospitals in Cologne (Kliniken der Stadt Köln) and Munich (Städtisches Klinikum München), among others (Philips 2019a, 2019b, July 12, 2018).

German Health Alliance (GHA)

The German Health Alliance (GHA) is an initiative of the Federation of German Industries (BDI) that emerged from the German Healthcare Partnership (GHP) and currently comprises 113 member organizations, including Philips. The companies within

PHILIPS

University Medical Center Utrecht

Universitätsklinik Rostock

Health Innovation Port

Alliances with German clinics

German Health Alliance

80 The pilot project *HerzEffektMV* merges patients' medical records and data from wearables into a Philips database that patients, health professionals and other healthcare service providers have access to. The Rostock University Medical Center coordinates all persons involved and is responsible for ensuring that patient care and treatment is adjusted immediately in accordance with any change in the patient data collected (Kindermann and Lindemann 2018: 55).

the network are based in different sectors such as industry, civil society, and science and research. The network aims to strengthen health infrastructure and improve access to health-related resources (GHA 2021).

For details on Philip's partnership with Huawei, see section →3.5.

SIEMENS

Städtisches Klinikum Braunschweig

Partnerships associated to Simenes Healthineers Digital Eco-system, i. a. with Combinostics

Partnership with Radboud University Medical Center and Technology expert Center regarding Syngo Breast Care

Partnerships with Novartis regarding biomarker tests

SIEMENS is engaged in a partnership with the municipal hospital in Braunschweig, Germany (Städtisches Klinikum Braunschweig) that focuses on the hospital's medical technology equipment (Handelsblatt 2018).

Siemens Healthineers has established nearly 2,000 partnerships in 50 countries as part of its Digital Ecosystem platform designed to provide participating healthcare providers access to digital health-related innovations. This includes, for example, Siemens Healthineers' collaboration with the firm Combinostics that uses its cNeuro cMRI application in brain imaging techniques for the early detection of neurodegenerative diseases (Siemens Healthineers March 6, 2018).

Siemens Healthineers is cooperating with the Netherlands' Radboud University Medical Center in Nijmegen at the Medical Innovation and Technology expert Center (MITeC) by developing new technologies for minimally invasive procedures with the help of imaging procedures and testing these in a practical clinical setting (Radboud University Medical Center Dec. 22, 2020). Another collaboration with the Radboud University Medical Center involves detecting breast cancer in its early stages. Syngo.Breast Care, an AI-powered application developed by Siemens Healthineers, is being used here to assist radiologists in evaluating large mammography datasets (Siemens Healthineers 2020b).

Siemens Healthineers is also partnering with Novartis in developing and bringing to market diagnostic biomarker tests (serum neurofilament light chain immunoassays, sNFL) used in diagnosing multiple sclerosis (MS) and other neurological disorders. This partnership is expected to increase Siemens Healthineers' expertise in developing clinical diagnostic solutions (Siemens Healthineers Sept. 21, 2020).

SAP

Iristrace

SAP.iO Foundry New York Initiative, i. a. Droice Lab

SAP is partnering with the startup Iristrace, which provides a cloud-based platform for optimizing workflows by making data collection and analysis more efficient. During the COVID-19 pandemic, Iristrace's COVID Patient Record Management app has been used to monitor real-time data for everything from bed occupancies to medical devices. The app supports healthcare service providers by allowing them to collect, analyze, and share information more efficiently. Stored in the SAP Data Warehouse Cloud, the collected data is analyzed by the SAP Analytics Cloud (SAP News Center Sept. 29, 2020).

Droice Lab, one of the startups at the SAP.iO Foundry program in New York, focuses on using AI to help physicians provide better care to patients. Targeting the merging and processing of patient data, Droice Lab has already merged 50 million patient records in collaboration with healthcare service providers and insurers across the United States and Europe (Galer 2020). Droice Hawk is AI-based medical data analysis technology designed to ingest and understand patient and medical data from diverse sources (SAP 2021a; Droice Labs 2021).

For a discussion of SAP's machine learning research in the Brain Age Project, see section →3.5.

SAMSUNG is partnering with Welldoc and the American Association of Diabetes Educators (AADE) on the launch of the Diabetes Wellness Program (DWP) (Rhew 2018).

Together with U.S. provider Kaiser Permanente, Samsung is developing a home-based cardiac rehabilitation program that uses Samsung smartwatches and the HeartWise app to monitor patients' heart rates and activities (Landi 2020).

Through a partnership with Medtronic, mobile devices can be used to monitor the health status of chronically ill patients (Rhew 2018).

Through collaborations with companies in the sports and fitness sector, such as Calm, Fitplan and Echelon, Samsung Smart TV users can access exercise units and instructions to take part in sports programs (Meskó et al. 2020: 54) (➔3.2).

In addition, Samsung is partnering with care providers in developing a coaching and wellness app to help monitor cardiac patients' health with the use of the Samsung Gear Watch (Meskó et al. 2020: 53; Rhew 2018).

Through its Samsung Biologics division, the company cooperates with various partners, including the biotech company Kineta, Inc. (Samsung Biologics 2020b).

Samsung is an official partner of Breezie (Breezie 2021a, 2021b).[81]

The tech giant is also engaged in a partnership with eCaring[82] that aims to optimize care management with the help of Samsung devices. The Samsung Galaxy Tab tablet plays a key role in these solutions. eCaring's customers include hospital chains and those providing nursing or home care services (Williams 2016; Belic 2015).

In a cooperation with Billy,[83] (formerly Curo), Samsung's SmartThings is used in home (remote) monitoring contexts for the elderly (Ray 2019). Samsung's Gear Watches and SmartThings technology are also used in a similar cooperation with Reemo[84] (Holland 2016b).

Information on Samsung's partnerships in the context of the Samsung Gear VR headset can be found in section ➔3.5.

Samsung's cooperation with American Well (Amwell) with the Live Health Online Platform is discussed in section ➔3.2.

SAMSUNG

Diabetes Wellnes Program with Welldoc and the American Association of Diabetes Educators

Partnerships regarding Samsung Smartwatches with i. a.

Kaiser Permanente

Medtronic

Calm

Fitplan

Echelon

Partnerships regarding Samsung Biologics, i. a. with Kineta

Further partnerships with health companies, i. a. with

Breezie

eCaring

Billy

Reemo

81 Breezie is an open platform designed for senior care providers. It allows providers to customize tablet interfaces and thus digitalize, personalize and extend the reach of the care they provide. Breezie can also serve as a voice-controlled assistant and be integrated into a smarthome environment (Breezie 2021b, 2021a).

82 *eCaring* is a software platform for nursing care providers that allows for the easy and intuitive documentation of care activities. Through the eCaring app, users can set reminders to take medication, and they can retrieve easy-to-read overviews of patients and their current requirements (eCaring 2020). According to eCaring, the app also collects patient-relevant clinical data, tracks data on their medications and behavior, and aggregates their data, thereby helping people in need of care stay at home and out of the hospital (Belic 2015).

83 Billy is a smarthome device used primarily in Australia that tracks the daily activities of seniors who wish to continue living at home. Billy is able to recognize changes in regular day-to-day activities and, after an initial familiarization phase, offer suggestions or alerts. The device is linked to an app that can share this information with family members or long-term care providers, for example. Billy learns using smart analytics and ML, but without the use of cameras or microphones. Instead, behavior is observed through motion and multipurpose sensors, which communicate with a hub that coordinates the input and sends signals to the app (Billy 2020).

84 Originally developed for use in smarthome devices, Reemo's gesture control technologies are now being developed for use in wearables designed for seniors. The technology is linked with a health monitoring platform through which movements, heart rates, current locations, etc. can be recorded and also allows for emergency calls to be made. This means that seniors stay connected with family members and other long-term care and health service providers, but can continue to live independently in their own homes (Holland 2017; Reemo Health 2021).

SONY
mSafety

SONY's mSafety is a comprehensive B2B platform in the mobile health and wellness services sector. The mSafety wearable device records data regarding a patient's or user's physical activity and exertion levels, their vital signs, and sleep patterns without requiring connection to a smartphone (Sony 2021b, 2021c).

HUAWEI
Partnership with Philips
Partnership regarding Visualized Drug Screening platform and Shennong Project website on Covid-19
Anti-Covid-19-Program

HUAWEI has been cooperating with Philips in China since 2016 by maintaining a cloud-based platform and Internet of Things (IoT) solutions for healthcare (Meskó et al. 2020: 49).

Huawei Cloud, in partnerships with the research institutions of Huazhong University of Science & Technology, Xi'an Jiaotong University, and Beijing Genomics Institute (BGI), has launched a Visualized Drug Screening Platform for COVID-19 and a website called the Shennong Project to support the development of drugs to treat COVID-19 (Huawei April 15, 2020; Meskó et al. 2020: 50). In addition, an AI-based diagnostic tool for the disease has been implemented using CTs at two collaborating hospitals in Ecuador (Quito Sur Hospital, Ceibos Hospital Guayaquil) in an effort to limit waiting times and to contain the spread of the disease (Meskó et al. 2020: 50).

Huawei Cloud has launched the Anti-COVID-19 Program, which provides business, technological and market support to Huawei Cloud business partners (Huawei Technologies Co., Ltd. April 7, 2020).

ALIBABA
Partnerships with healthcare providers
Global MediXchange for Combating Covid-19
Partnerships with GlaxoSmith Kline

ALIBABA's health division, Alibaba Health Information Technology Limited, is engaged in partnerships with 23,000 healthcare service providers, including physicians, pharmacists and nutritionists, who carry out more than 50,000 online consultations every day (Meskó et al. 2020: 60).

The Alibaba Foundation is a participating partner in the Global MediXchange for Combating COVID-19 (GMCC) program, which aims to facilitate online communication and collaboration across borders in the context of the COVID-19 pandemic through AI and cloud computing capabilities (Meskó et al. 2020: 61).

In April 2019, Alibaba and GlaxoSmithKline (GSK) launched a joint business plan to establish a healthcare strategy built on big data, marketing models and innovative service offerings for the Chinese market. The companies aim to improve outreach to Chinese customers and provide more effective health services (GlaxoSmithKline April 2, 2019).

For a discussion of Alibaba's Ali Health partnership with Bo'ao Winhealth Rare Disease Medical Center, see section →3.5.

TENCENT maintains partnerships with the pharmaceutical companies Merck and Novartis (Choueiri et al. 2020: 5). Tencent and Merck entered into a strategic collaboration agreement in 2019 that has several aims, including the creation of improved access to healthcare services through digital platforms and more patient-centric healthcare management. Tencent plans to bring AI, big data and cloud computing capabilities to the collaboration. The use of digital products and services is expected to improve public knowledge of various medical conditions and diseases, including their symptoms and treatment options (Merck Group Jan. 23, 2019). Novartis and Tencent have teamed up for the AI Nurse project, an AI-based disease management tool developed specifically for the Chinese market and for people suffering from heart disease. Patients can use the tool to document and monitor their own vital signs, while also communicating them to clinical staff and physicians. The goal here is to prevent or at least push back a return visit to the hospital (Novartis 2020, 2021).

In another partnership, Tencent and Huma[85] are working together to establish and build a network for research on Parkinson's disease. The two firms are working together on a study to determine how smartphone cameras can be used to detect the progression of the disease (Huma 2021b, 2021c).

For a discussion of Tencent's partnership with Babylon Health, see section →3.2. For details on Tencent's partnership with RareStone, see section →3.5.

TENCENT

Partnerships with pharmaceutical companies, i. a.:

Merck

Novartis

Partnerships with companies, i. a.:

Huma

Babylon Health

RareStone

Tech giants maintain a tremendous variety of partnerships and networks through which they carry out a vast array of healthcare projects and programs. Given the sheer number and broad scope of these efforts, which range from short-term projects to long-term alliances, it is difficult to maintain a clear overview of all of them. In most cases, partnerships and alliances are cultivated between universities, government healthcare agencies, private healthcare institutions, other tech companies and pharmaceutical companies.

85 Huma (formerly Medopad) is a software startup that uses digital biomarkers to facilitate proactive patient monitoring through wearables and apps (Plato Technologies Inc. Apr. 16, 2020; Huma 2021a).

INVESTMENTS AND SPIN-OFFS

Tech giants are also expanding through their corporate venture capital (CVC) equity investments. This kind of activity involves investing capital in external healthcare startups and / or in-house spin-offs. From 2016 to 2020, annual investments by GAFAM companies alone increased from 13 to 38 investment deals, with Google leading the pack at 15 such investments, followed by Amazon with 14. The number of investments made by GAFAM companies in 2021 was 36 (CB Insights 2021).

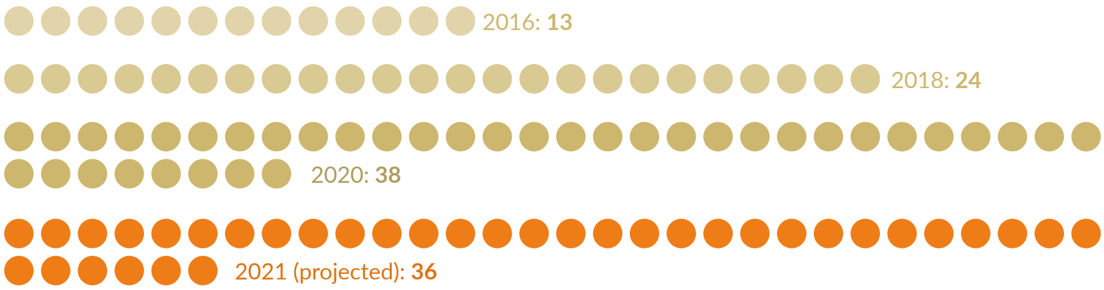


FIGURE 11: **Annual investment activity, GAFAM companies**
Source: Authors. Data: CB Insights 2021, Bertelsmann Stiftung

GOOGLE / ALPHABET
23andme
Doctor on Demand
Flatiron Health
Clover Health
Decibel Therapeutics
Collective Health
Spruce Health
SpyBiotech
Verily
Oscar Health
Practo Technologies

GOOGLE / ALPHABET – The phrase "The Alphabet of Investment" (Meskó et al. 2020: 9) has been invoked to refer to the fact that the tech giant has invested massively in other firms, including numerous healthcare companies (Juul 2019; Prendergass 2018).[86] Referred to as Google Venture (GV), the company invests primarily in life sciences and in so-called frontier tech. Of particular interest to the company are those businesses active in healthcare services, health information technology, diagnostics and therapy, as well as AI, robotics and hardware development (Meskó et al. 2020: 9). Firms such as 23andme, Doctor on Demand, Flatiron Health, Clover Health, Decibel Therapeutics, Collective Health, Spruce Health, and SpyBiotech are among just a few examples of companies in which Google Venture (GV) has invested (Prendergass 2018).

CapitalG, another investment arm of Alphabet, is also funding companies such as Verily Life Sciences, LLC (Verily), Oscar Health and Practo Technologies with venture capital (Prendergass 2018; Meskó et al. 2020: 10). Having started as a research project within Alphabet's research division X Development LLC, Verily was later spun off to become its own division. Since then, it has been involved in numerous research projects as an independent research company in the life sciences (Pousttchi et al. 2019; Meskó et al. 2020) (→3.5).

23ANDME is a U.S. biotech company that analyzes individuals' genetic data. Its analyses are based on submitted saliva samples that are screened for genetic diseases, other predispositions, and information on geographic origin (23andMe 2021a, 2021b).

DOCTOR ON DEMAND is a U.S.-based online video telemedicine company (Doctor On Demand 2021).

86 In 2019, Google / Alphabet, along with Microsoft and Tencent, were responsible for more than 70 % of all investments in digital health companies and startups. With 57 companies in its portfolio for that year, Google / Alphabet was the most active investor (Meskó et al. 2020: 9).

FLATIRON HEALTH is a U.S. healthcare technology company that works with cancer centers and companies in the field to accelerate cancer research and improve the quality of cancer care by extracting meaningful information from cancer patient data (Flatiron Health 2021).

CLOVER HEALTH is a U.S. health insurance company (Clover Health 2021).

DECIBEL THERAPEUTICS is a U.S. biotech company dedicated to developing therapies designed to restore or improve hearing and balance (Decibel Therapeutics 2021).

COLLECTIVE HEALTH is a U.S.-based tech company that provides a health benefits platform intended specifically for employees. The platform provides an overview of the scope of health services provided by a wide range of companies and helps users find the service they need (Collective Health 2021; Hackett 2021).

SPRUCE HEALTH is a U.S.-based company developing a telemedicine platform providing video telephony communication between doctors and patients, digital payment options and digital reminders of consultations (Spruce 2021).

SPYBIOTECH is a UK company that has developed a platform to accelerate vaccine development for infectious diseases, cancer and chronic illnesses (SpyBiotech 2021).

AMAZON invests in GRAIL, while its offshoot, Amazon Alexa, invests in Owlet Baby Care and Aaptiv (Prendergass 2018).

GRAIL is a U.S.-based biotech startup in the field of early cancer detection. It was founded in 2016 and has since received funding from a variety of investors, including Bill Gates, Bezos Expeditions, Google Venture (GV), Tencent and Johnson & Johnson. GRAIL aims to improve early diagnoses in oncology through blood testing and is conducting a large clinical trial in genomic medicine (Shih 2018; Crunchbase 2021b; Grail, Inc. 2017).

OWLET BABY CARE is a U.S.-based company providing monitoring products and technologies, including a surveillance camera and sleep monitoring capabilities, for use in monitoring newborn and infant health (Owlet Baby Care 2021).

AAPTIV offers a workout app that combines workouts with coaching and music offerings during a workout (Aaptiv 2021).

AMAZON
GRAIL
Owlet Baby Care
Aaptiv

APPLE's spin-off is active in developing the company's proprietary AC Wellness clinics (AC Wellness 2020) (➔3.4.5).

APPLE
AC Wellness

MICROSOFT invests in companies such as DNAnexus and Welltok, and supports firms like Kinestica, Eva Diagnostics / Entia and NIBS NeuroScience Technologies and Jintronix as part of its own Microsoft ScaleUp program (Prendergass 2018).

DNANEXUS is a U.S.-based company that has created a global network for genomic medicine through the use of cloud computing and bioinformatics (DNAnexus 2021).

WELLTOK is a U.S. company providing an ML-enabled platform in the healthcare and other sectors (Welltok 2021).

KINESTICA is a Slovenian medical device company that designs, develops and markets medical devices for use in sensor-based and virtual reality-assisted therapeutic systems that are applied in neurorehabilitation efforts (Kinestica 2021).

EVA DIAGNOSTICS / ENTIA is a UK medical technology company that develops virtual oncology solutions designed to improve cancer treatments (Entia 2021).

NIBS NEUROSCIENCE TECHNOLOGIES is an Israeli company that has developed a system targeting the non-invasive monitoring, evaluation and treatment of brain diseases (NIBS NeuroScience Technologies 2021).

JINTRONIX is a Canadian company focused on developing 3D biomedical software for use in physical and cognitive rehabilitation efforts (Jintronix 2020).

MICROSOFT
DNAnexus
Welltok
Microsoft ScaleUp Program, i. a.:
Kinestica
Eva Diagnostics / Entia
NIBS
NeuroScience Technologies
Jintronix

IBM
Pathway Genomics / OmeCare
ApoGen Biotechnologies
Petra Pharma
Modernizing Medicine

IBM Watson is providing venture capital to healthcare companies such as Pathway Genomics / OmeCare, ApoGen Biotechnologies, Petra Pharma and Modernizing Medicine (Prendergass 2018).

PATHWAY GENOMICS / OMECARE is a U.S. company that performs DNA laboratory analyses to determine genetic dispositions (OmeCare 2021).

APOGEN BIOTECHNOLOGIES is a U.S. biotechnology company focused on developing a new approach to cancer therapy that eliminates the development of drug resistance in patients (ApoGen Biotechnologies 2021).

PETRA PHARMA is a U.S.-based pharmaceutical company with specialization in novel enzyme targets, which are important in the development of therapies for cancer and metabolic diseases (pre-IPO Pharma 2021).

MODERNIZING MEDICINE is a U.S. company that developed the Electronic Medical Assistant, a cloud-based electronic health record (EHR) system (Modernizing Medicine 2021).

INTEL
Sano
Minha Vida

INTEL's investment arm Intel Capital invests venture capital in several healthcare companies, including Sano and Minha Vida, a health and wellness portal founded in 2004 (Prendergass 2018; Intel Corporation April 5, 2012).

SANO is a U.S. company specializing in the development of sensors designed to measure metabolic data (Lavine June 6, 2015). Sano was acquired by One Drop in 2020 (One Drop April 13, 2020).

PHILIPS
Mytonomy
Carevive Systems
Orbita
Bright.md
Babyscripts
LindaCare
DEARhealth
LeQuest
Xealth

PHILIPS invests as Philips Ventures[87] and Philips Health Technology Ventures Fund in more than 100 health-related startups, including Mytonomy, Carevive Systems, Orbita, Bright.md, Babyscripts, LindaCare, DEARhealth, LeQuest and Xealth (Philips 2021g).

MYTONOMY is a U.S.-based company focused on cloud-based services in the healthcare sector that include an online health education platform for patients (Philips March 22, 2018).

CAREVIVE SYSTEMS is a U.S.-based company that has developed a platform for cancer care management designed to improve patients' experience with treatment. The platform supports health professionals with developing personalized treatment plans and provides patients information regarding the general course of cancer therapies (Vaidya 2021).

ORBITA is a U.S.-based tech company developing AI solutions for use in voice recognition technologies and chatbot applications. This AI solution is designed to help healthcare institutions and healthcare providers provide their patients with virtual healthcare assistance (Orbita May 28, 2020).

BRIGHT.MD is a U.S.-based company focused on creating opportunities to automate processes in the healthcare sector. The company's flagship project, SmartExam, is an AI-powered telemedicine platform that has already been integrated into the systems used in several hospitals across the United States and Canada (Bright.md May 27, 2020).

BABYSCRIPTS is a U.S.-based company providing a virtual obstetrics care management platform for mothers and babies during pregnancy, birth and the first few years of a child's life (Muoio 2019).

LINDACARE is a startup focused on cloud-based remote monitoring solutions. The LindaCare OnePulse platform, which is designed specifically for patients with implantable cardiac electronic devices, is partnering with Philips' IntelliSpace to improve follow-up care (LindaCare Aug. 28, 2019).

DEARHEALTH is a U.S. company that emerged from a University of California (UCLA) project. DEARhealth provides AI-based solutions for personalized chronically ill care (DEARhealth July 18, 2019).

LEQUEST is a Dutch company that develops digital, interactive and simulation-driven training technology for healthcare professionals to improve their use of medical devices and software. LeQuest and Philips are collaborating to combine these online training opportunities with Philips' Affiniti ultrasound system. The combination of the two systems aims to improve clinical workflow efficiency and clinical professionals' understanding of how the devices and software work, as well as their ability to handle them (Philips Oct. 7, 2020).

XEALTH is a U.S.-based company with a platform for managing digital health solutions that makes it easier for medical staff to identify effective digital health tools for patients (Xealth June 20, 2019).

87 Philips Ventures' mission is to foster collaborations with and investments in healthcare startups in the areas of health promotion, prevention, diagnostics, therapy and home care services. At the company's centers around the world, Philips' innovation team, investment team, and operations team provides startups assistance with the development process (Philips 2021g, 2021k).

SIEMENS spun off its medical technology business in 2016 in the form of Siemens Healthineers (Siemens Healthineers 2021v).

SIEMENS
Siemens Healthineers

ALIBABA has investments in the Chinese hospital chain Meinian OneHealth. Back in 2017, Alibaba Cloud formed a collaboration with Meinian to improve its cloud computing platform. As of 2019, Alibaba owned 14.4 % of the chain's shares (Tuna 2019b; Shumin 2019, 2020).

ALIBABA
Meinian OneHealth

TENCENT invests in several health-related startups and partners with some of them. Examples include Shuidi, iCarbonX, inui Health (Scanadu), Karius, HomeHero, CliniCloud, and Circle Medical (Farr 2017; Varadharajan 2017; Bruno 2019).

SHUIDI (also known as Waterdrop) was founded in 2016 and operates multiple healthcare platforms. The company aims to use crowdfunding as a means of supporting the Chinese health insurance system (Bruno 2019; PitchBook 2021).

ICARBONX is a Chinese startup founded in 2015 that delivers AI-powered genomic data analysis and is often hailed as a unicorn in the biotech field (iCarbonX 2021; Varadharajan 2017).

INUI HEALTH (previously Scanadu) is a U.S. medical technology company engaged in the development of tools such as medical wearables (Livingston April 27, 2015). After relaunching in 2020 under its new name, inui Health, the company was acquired by Israeli startup Healthy.io. inui Health has focused on developing a smartphone-based in-home urine testing system and a digital platform. inui Health continues to receive funding from Tencent (Farr 2020).

KARIUS is a U.S. biotech company that was founded in California in 2014. It develops technologies that use DNA fragments obtained from blood tests to detect infectious diseases in their early stages (Ravet 2017).

HOMEHERO is a U.S. company founded in 2014 offering a platform for hiring in-home caregivers. It features an online portal where users can view potential caregivers' ("Heros") video profiles and background checks (HomeHero June 30, 2015).

CLINICLOUD is an Australian startup with headquarters in California (Crunchbase 2021a). The company has developed a digital stethoscope and a non-contact medical thermometer for at-home use. Both devices connect with an app and store the user's recorded vital-sign data on their smartphone or on a cloud server (Lim 2015).

CIRCLE MEDICAL is a U.S. company that has developed an app that allows patients to contact and consult with physicians. The app can be used for emergencies as well as preventive care (Pai 2015).

TENCENT
Shuidi
iCarbonX
inui Health
Karius
HomeHero
CliniCloud
Circle Medical

Tech giants are investing heavily in external companies and their own spin-offs. In some cases, they are establishing extremely complex corporate structures that are active in different areas of the healthcare sector. Health-related AI startups are the preferred recipients of most of these investments.

ACQUISITIONS

Another strategy pursued by tech giants looking to expand into the healthcare sector is to acquire external companies and startups.[88] While GAFAM companies' investment activities have risen steadily since 2016, a downward trend can be observed with regard to annual acquisitions, as the number dropped from 50 to 35 over the same period. With only 16 buyouts projected for 2021, the downward trend continues (CB Insights 2021).

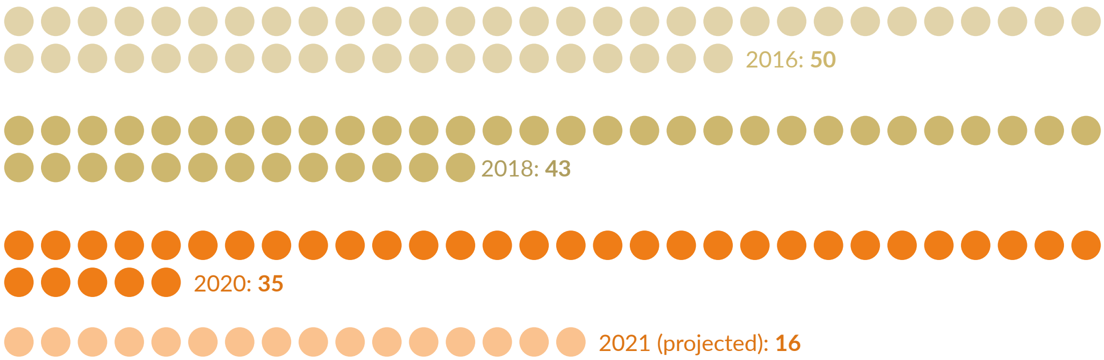


FIGURE 12: **Annual acquisitions, GAFAM companies**
Source: Authors. Data: CB Insights 2021, Bertelsmann Stiftung

GOOGLE / ALPHABET
DeepMind
Fitbit

GOOGLE / ALPHABET acquired London-based Artificial General Intelligence (AGI) startup Deep-Mind in 2014 and smartwatch producer Fitbit in late 2019 (Meskó et al. 2020: 10-16).

APPLE
Gliimpse
Beddit

APPLE acquired Gliimpse in 2016, which built a personal health data platform for aggregating and sharing health data (Meskó et al. 2020: 19). In 2017, Apple acquired the startup Beddit, which develops sleep tracking devices that can be connected to apps designed for iPhones and Apple Watches (Krishnan 2019; Meskó et al. 2020: 19).

META (formerly Facebook)
Moves
Oculus
CTRL-Labs

META (formerly Facebook) acquired the fitness software provider Moves and virtual reality pioneer Oculus in 2014 (Prendergass 2018; Constine 2014). In 2019, the tech giant acquired the startup CTRL-Labs, which uses software to "[develop] the technology to control digital devices with your mind" (Wagner 2019a; Woopen et al. 2020: 4).

88 According to the October 2020 report examining competition in digital markets published by the U.S. Congress' Subcommittee on Antitrust, Commercial and Administrative Law, acquisitions are a commonly pursued strategy by the market-dominant tech giants Facebook (now Meta), Google, Amazon and Apple (Subcommittee on Antitrust, Commercial and Administrative Law 2020).

AMAZON acquired in 2019 the telemedicine company Health Navigator, which features an online symptom-checking tool that allows for a remote diagnosis (Shope 2019; Krüger-Brand 2020: 376-377). By allowing Amazon to provide “diagnostic and clinical management software, as well as smart language processing services” (Krüger-Brand 2020: 377), the acquisition will help the tech giant position itself in the telemedicine healthcare market (Meskó et al. 2020: 34). Amazon shook up the pharmaceutical sector in 2018 when it acquired the online pharmacy PillPack (Meskó et al. 2020: 34-35) (➔3.4.7).

AMAZON
Health Navigator
PillPack

MICROSOFT acquired Nuance Communications Inc., a speech recognition and AI company, for $ 20 billion in spring 2021. Nuance is increasingly focusing on the medical sector, offering software packages for healthcare professionals that can, for example, process dictation for medical reports. Voice recordings are stored in the cloud, where they are then connected with the technical libraries of individual research facilities (tagesschau.de 2021c; Microsoft News Center April 12, 2021).

MICROSOFT
Nuance

IBM acquired Truven Health Analytics, Merge Healthcare, Explorys, and Phytel in 2015 and 2016 (Prendergass 2018; Rhee 2021).

TRUVEN HEALTH ANALYTICS provides analytic services with health data as part of IBM Watson Health (IBM 2021g).

MERGE HEALTHCARE provides AI imaging solutions as part of IBM Watson Health (IBM 2021f).

EXPLORYS, as part of IBM Watson Health, offers a cloud-based platform that relies on electronic medical record data and provides analytic tools for use in evaluation processes. Open to life sciences companies, the platform is expected to help battle data silos in healthcare (IBM 2021d).

PHYTEL is developing automated solutions as part of IBM Watson Health to promote patient engagement (IBM 2020e).

IBM
Truven Health Analytics
Merge Healthcare
Explorys
Phytel

INTEL acquired Israeli startup IDesia Biometrics in 2012 (Prendergass 2018; Savitz 2012).

IDESIA BIOMETRICS offers biometric authentication solutions (Idesia Biometrics 2021).

INTEL
IDesia Biometrics

PHILIPS acquired ultrasound equipment producer ATL Ultrasound in 1998. In 2000, it acquired nuclear medicine specialist ADAC Laboratories and home-care specialist Agilent Technologies Healthcare Solutions Group. This was followed in 2001 by the acquisition of the medical division of the British group Macroni (Kindermann and Lindemann 2018: 40).

PHILIPS
ATL Ultrasound
ADAC Laboratories
Agilent Technologies Healthcare Solutions Group
Macronis medical division

SIEMENS
Dade Behring
MobileMD
Penrith
Neo New Oncology
Medicalis
Conworx Technology
Epocal
Fast Track Diagnostics
Corindus Vascular Robotics
Varian Medical Systems

SIEMENS and Siemens Healthineers (since 2016) carried out a series of acquisitions from 2007 to 2021, which have included the following companies: Dade Behring, MobileMD, Penrith, Neo New Oncology, Medicalis, Conworx Technology, Epocal, Fast Track Diagnostics (FTD), Corindus Vascular Robotics and Varian Medical Systems (Crunchbase 2021c).

DADE BEHRING is a U.S. company that specializes in laboratory diagnostics, and in-vitro diagnostics in particular (Siemens Healthineers 2021f).

MOBILEMD is a U.S. company that develops the technology for health information exchange services that increase connectivity among healthcare providers and institutions (Miliard 2011).

PENRITH, a U.S. company, is developing ultrasound imaging systems (Arrowsmith Aug. 22, 2012).

NEO NEW ONCOLOGY, a German medical company, is developing the NEO cancer diagnostics platform, which enables physicians to find customized treatment options for their patients (VentureCapital Magazin 2016).

MEDICALIS, a U.S. company, is developing an imaging clinical decision support tool and solutions designed to increase operational efficiency across multivendor environments and thus optimize workflows (Miliard 2017).

CONWORX TECHNOLOGY, a German company, offers point-of-care testing (POCT). The company also develops interface and data management solutions (Siemens Healthineers Nov. 8, 2016).

EPOCAL, a Canadian company, develops blood gas diagnostic procedures as well as point-of-care solutions for measuring blood gas levels (Lück 2017).

FAST TRACK DIAGNOSTICS (FTD), a Luxembourg-based company, develops molecular diagnostic tests for infectious diseases. Unlike other clinical tests, FTD's tests can differentiate "between viral, bacterial and other infectious diseases" (Siemens Healthineers Dec. 15, 2017).

CORINDUS VASCULAR ROBOTICS, INC., a U.S. company, as one of the world's top robotic systems specialists, developed the CorPath GRX, a robotic platform for vascular intervention procedures (Siemens Healthineers Oct. 29, 2019, 2021e) (→3.4.4).

VARIAN MEDICAL SYSTEMS, INC. is a U.S. medical technology company that uses AI to develop therapies for the early detection of diseases such as cancer, as well as treatment and radiation therapies, and imaging software (Höpner 2020). For example, the company developed the ARIA information system, which consolidates cancer patients' data into an electronic health record (EHR) (Siemens Healthineers 2021r). The company's acquisition by Siemens Healthineers was completed in April 2021 (Siemens Healthineers April 15, 2021).

TENCENT
Tencent Trusted Doctors

TENCENT's offshoot Tencent Trusted Doctors, which emerged from the merger of Tencent Doctorwork and the startup Trusted Doctors, acquired 25 clinics in 2019 (Tuna 2019a; Meskó et al. 2020: 62).

As a result of their massive financial volume, today's tech giants can take over successful startups to bundle capacities and thereby expand their market position even further. Their activities in this area focus primarily on acquiring AI and telemedicine startups.

3.4.10 SUMMARY

The tech giants are active in different ways in all aspects of healthcare provision, but to varying degrees of intensity. Healthcare cloud computing, which is used to organize, manage and analyze complex healthcare data for a variety of purposes, is an extremely important area for the tech giants. They are also somewhat active in the area of blockchain technology, which can improve data flow traceability and help ensure the security of those from whom the data originates. Tech giant processes and products in areas such as medical imaging are taking on an ever-growing role in the medical technology and biotechnology sectors. There are only a few cases of tech giants creating structures for the provision of medical services, most of which relate primarily to hospitals and networked systems for healthcare staff in particular.

Tech giants have become increasingly active in different areas of the pharmaceutical supply chain industry. While their products and services are primarily found in the areas of distribution and logistics, they are also engaged in manufacturing. The products and services offered by tech giants in areas such as robotics, mobility and logistics, and health insurance have thus far played a minor role in the healthcare sector. Tech giants nurture a wide variety of partnerships and networks through which they can conduct short-term joint projects on clearly defined issues and also form long-term alliances within the sector. Primarily, they cultivate partnerships and alliances with universities, government healthcare agencies, private healthcare institutions, other tech giants and pharmaceutical companies. Tech giants are exceptionally active in investing in other companies, fostering spin-offs, and engaging in acquisitions, generally preferring to invest in or buy up health-related AI startups.

Due to their high market penetration – which is largely a result of their vast (technological) expertise and access to massive amounts of data – tech giants are increasingly taking on an outsized role in the healthcare sector. By optimizing the means of preventive and personalized medicine, their products, services and structures can contribute to improved and more efficient healthcare provision. However, there are risks involved as traditional stakeholders could become dependent on the tech giants' expertise, capacities and resources. This vulnerability could be exacerbated by the tech giants' steadily growing dominance in markets beyond the healthcare sector as well. The ongoing facilitation of networking within the healthcare sector and between the healthcare and lifestyle sectors by technology could radically transform established healthcare structures and the distribution of responsibilities among stakeholders. This could go so far as to create new, parallel structures in healthcare provision. The ethical issues associated with this dynamic are discussed in chapter → 4.

3.5 SCIENCE, RESEARCH AND DEVELOPMENT

Science and research allow for the systematic and methodic acquisition, reflection and dissemination of knowledge. Article 5 (3) of the German constitution, the Basic Law, guarantees the freedom of science, research and teaching. The term "research and development (R&D)", commonly used in the corporate context, is defined as the "search for new knowledge using scientific methods and in a planned form," according to which research is understood as "the general acquisition of new knowledge" and development as "its initial concrete and practical implementation." The knowledge gained can "extend to products as well as to (manufacturing) processes and product as well as process applications" (Voigt 2018).

When it comes to research on large and diverse sets of data, which is the primary focus of the tech giants, research and development is first and foremost about finding correlations through the use of AI-supported big data applications (→3.1). Informatics technologies are expected to "significantly change and even improve the process of gaining scientific knowledge" (Wiegerling et al. 2019, S. 402). The following are examples of the activities of tech giants in science as well as in R&D.

ALPHABET's subsidiary Calico Life Sciences, LLC. (Calico), Verily Life Sciences, LLC. (Verily) (formerly Google Life Sciences), and Google DeepMind (Health) are establishing a strong presence in health-related research (Kohlhagen 2019: 53).

Calico has been operating as a biotechnology company since 2013 and is "one of Google's most ambitious ventures" (Kohlhagen 2019: 53). The aim of Calico is to research the processes of human aging and use that data to help people live long and healthy lives (Calico 2021). Calico partners with numerous companies in the biotechnology sector as part of that work. For example, it has a partnership with C4 Therapeutics to conduct research into new medicines and another with AbbVie for research and development focused on new treatments for age-related diseases (Calico July 27, 2021, March 23, 2017).

As an independent research company in the field of life sciences, Verily is involved in numerous collaborations and projects of various kinds (Kohlhagen 2019: 53). Started as a research project within Alphabet's X Development LLC. research division, the company spun Verily off in 2015. The goal is to research and develop technologies and applications for collecting and analyzing health data (Verily, n. d.). "Our mission is to harness the world's health data so we can live healthier lives," says Jessica Mega, Verily's medical and scientific director. (Schulz 2018: 94).

Verily, in collaboration with Stanford Medicine and the Duke University School of Medicine, is conducting a reference study: the Project Baseline Health Study. Molecular, genetic, psychological and other data have been collected from 10,000 participants since 2017. The test subjects are set up with mobile sensors and undergo weekly examinations. The goal of the study is to "map the whole health of a person" (ibid: 107) and determine what makes a person truly healthy (Verily 2021a; Schulz 2018: 107).

GOOGLE / ALPHABET

Calico

Verily

Google Health & Health Studies App

DeepMind Health

Googles Breast Cancer Weight Loss Study

Google Research

Verily has extensive strategic alliances with the pharmaceutical companies Ostuka, Novartis, Pfizer and Sanofi to advance clinical research. Among other things, support is to be provided for optimized recruitment possibilities and the participation of test subjects in studies. For example, Verily uses health-related Google searches to identify potential study participants (Farr 2019a). The company is also conducting further research projects on the development and use of robotics, AI and virtual reality (VR) in the field of surgery (Schulz 2018: 94).

Google Health, through its support of DeepMind Health[89] (➔3.4.9), is running diverse AI-based, health-related research projects in the field of medical imaging and diagnostics as well as in genomics. To that end, it is partnering with numerous healthcare providers as well as state-managed and academic institutions (Google Health n. d. c, n. d. d). For example, Google Health is carrying out a study on AI-based early detection of acute renal failure (Tomašev et al. 2019; DeepMind July 31, 2019). Google DeepMind Health is collaborating with Northwestern Medicine on a clinical trial to explore how AI can improve the diagnosis of breast cancer, and other maladies (McKinney et al. 2020; Google, February 25, 2021). In another study, DeepMind Health is partnering with the Moorfields Eye Hospital National Health Service Foundation Trust and the University College London (UCL) Institute of Ophthalmology to develop AI-based retinal disease detection applications to assist ophthalmologists (DeepMind, August 13, 2018; Fauw et al. 2018). In a study published in 2020, DeepMind Health reported that an AI-based retinal imaging diagnostic solution it developed could detect age-related macular degeneration with the same or greater precision – compared to ophthalmologists – and predict the progression of the disease within the next six months (Yim et al. 2020; Wiggers 2020).

Google's Breast Cancer Weight Loss Study (BWEL) is a collaborative study conducted together with the U.S. National Cancer Institute and the Dana-Farber Cancer Institute. Being overweight or obese is associated with a higher risk of breast cancer and recurrence (Dana-Farber Cancer Institute, April 27, 2016). The BWEL study[90] seeks to prevent cancer recurrence by bolstering participants' health-promoting behaviors. As part of the study, a virtual care network of patients, healthcare professionals and researchers is to be built, along with a database to discover relationships between activities, sleep cycles and dietary habits and improve prevention options (Dana-Farber Cancer Institute, October 11, 2016; Ligibel 2019; Wicklund 2018).

Google Research is engaging in technology-enabled research and development to solve challenges in diverse research fields, including health and life sciences. That includes human-computer interaction to support the research (Google Research n. d.).

The Google Health Studies app is designed to encourage patient and user participation in health-related studies by allowing participation within the app (Google Play Store 2021b).

89 The DeepMind Health division was merged into the Google Health division in 2019 (King 2019).

90 The BWEL study includes a total of 3,200 overweight and obese participants from the United States and Canada with stage II and stage III breast cancer. The study began in August 2016. Participants were divided into two groups. Group 1 is provided with health education on healthy eating and exercise. Group 2 receives the same educational program as well as a personal mHealth coach (Ligibel 2019). This is made possible through a partnership with Fitbit. The company's Fitbit Charge HRTM fitness tracker is used to record a person's activities and pulse. In addition, the Fitbit Aria Wi-Fi Smart Scale is used to measure weight, BMI, lean mass and body fat percentage and link them to an online Fitbit profile. The total package is rounded out with the FitStarTM, a video-based exercise service available to participants on their mobile devices (Dana-Farber Cancer Institute, April 27, 2016).

APPLE is providing software development kits (SDKs) as open source to support researchers and developers in developing further applications for smartphones (Krishnan 2019).

Since 2014, Apple has offered digital interfaces (APIs) for smartphones with the HealthKit, with which users can provide their health data (Horton 2020). For example, the blood glucose values of HealthKit users were used in a study to develop a new model for predicting blood glucose levels in type 1 diabetics (Miller et al. 2020).

The ResearchKit, launched in 2015, is designed to help develop mobile applications that can collect data and information for medical research purposes (Kohlhagen 2019: 52). This can facilitate the recruitment of test persons, the collection of relevant examination parameters using a smartphone in everyday life and the coordination of medical studies in their entirety.

CareKit, launched in 2016, aims to help develop mobile apps that facilitate improved home care, particularly for chronic conditions and pre- and post-operative care (Krishnan 2019).

In partnership with the Stanford University School of Medicine, Apple conducted what it has dubbed the Apple Heart Study (AHS) to evaluate the accuracy of its Apple Watch's ECG function in diagnosing irregular heart rhythms such as atrial fibrillation (Stanford Medicine 2021).

Similarly, a study was conducted in collaboration with Stanford University on how app use can predict cognitive abilities in older adults (Gordon et al. 2019).

The Healthcare Innovation Lab at the Stanford University School of Medicine is conducting a COVID-19 Wearable Project to detect COVID-19 using wearables such as the Apple Watch (Stanford Healthcare Innovation Lab n. d.).

Together with the University of Tübingen, a study was published to provide insights into what smartphone use can reveal about the mental and cognitive state of users (Rauber et al. 2019).

In addition, a study was conducted in collaboration with Eli Lilly and Company and Evidation Health, Inc. to develop parameters that enable wearables to identify cognitive decline (Chen et al. 2019).

As part of the Apple Women's Health Study, the Harvard T.H. Chan School of Public Health worked together with Apple and the National Institute of Environmental Health Sciences (NIEHS), a National Institute of Health (NIH), to gain insights into how different factors can affect the menstrual cycle and gynecological diseases. Cycle data from the iPhone and / or Apple Watch will be used to develop innovative products for use in this field. (Harvard T.H. Chan 2021).

In collaboration with the American Heart Association (AHA) and the Brigham Research Institute at Brigham and Women's Hospital (BWH), the Apple Heart and Movement Study will examine the relationships between physical activity and heart health. The aim is to gain a better understanding of early warning signs and to support interventions in this area (BWH 2021).

The Apple Hearing Study examines noise exposure and its effects on hearing health through a partnership between the University of Michigan School of Public Health and Apple. The noise exposures of test persons through headphones and ambient noise are measured over the long term to generate insights into the effects. According to the University of Michigan School of Public Health, the study results will help inform public health policies and preventive measures for maintaining hearing health (University of Michigan 2021).

APPLE

HealthKit

ResearchKit

CareKit

Apple Heart Study

Covid-19 Wearables Project

Apple Women's Health Study

Apple Heart and Movement Study

Apple Hearing Study

Further studies with universites and healthcare institutions

Apple Research App

Apple's Research App is designed to allow Apple smartphone and smartwatch users to independently coordinate their participation in Apple studies. The app informs users about current studies on issues like women's health, autism diagnostics and treatments for Parkinson's disease (Apple 2021c).

META
(formerly Facebook)
fastMRI
facebook
The Human Cell Atlas Project

META (formerly Facebook) has a division called Facebook AI Research (FAIR), which is working together with New York University (NYU) Langone Health on a research project called fastMRI. The goal is to generate MRI scans more quickly by using AI to create high-quality imaging from lower-resolution image data that is captured at a faster rate (fastMRI 2020; Choueiri et al. 2019: 5). More broadly, FAIR is working to advance AI in both basic and applied research through collaborations (Facebook AI 2020a; Pousttchi et al. 2019).

The social network facebook is a significant tool in terms of recruiting study participants in behavioral health research by reaching potential subjects whose recruitment might otherwise be difficult (Pedersen and Kurz 2016).

Together with his wife Priscilla Chan, founder and CEO Mark Zuckerberg established the Chan Zuckerberg Initiative, LLC. (CZI) in late 2015 with the aim of researching and developing new treatments (Krüger-Brand 2020: 377; Crow 2017; Kutter et al. 2016). Chan and Zuckerberg's vision is "to cure, prevent or manage all diseases by the end of this century" (Crow 2017: 767). In this context, the Human Cell Atlas Project is a vital effort to build a public database bringing together diverse molecular data from hundreds of laboratories into a single atlas of human cell types. Within that project, CZI is partnering with the Wellcome Trust's Sanger Institute, the Chan Zuckerberg Biomedical Research Center (CZ Biohub) and committee members from numerous institutions. The CZ Biohub is an independent non-profit organization founded by Chan and Zuckerberg in San Francisco that is helping to implement CZI's vision by developing technology platforms for medical research (Crow 2017: 768). The CZ Biohub maintains partnerships with the American universities UC Berkeley, UCSF and Stanford (CZ Biohub 2020).

AMAZON
Amazon Web Services, i. a.:
Beth Israel Deaconess Medical Center
University of California, San Francisco
Grand Challenge / 1492 / Amazon X
Fred Hutchinson Cancer Research Center

AMAZON's cloud-based solution Amazon Web Services (AWS), including Amazon Neptune Technology, is being used for numerous research projects, including, for example, at the U.S.-based Beth Israel Deaconess Medical Center, to explore the potential of machine learning (ML) for healthcare. In response to the COVID-19 pandemic, the company is working together with the University of California, San Francisco (UCSF) on a program in which AWS-assisted genome sequencing is used to acquire insights into COVID-19 and other infectious diseases (Meskó et al. 2020: 37-38).

Amazon's health division also has a small group of researchers, Grand Challenge, that also operates under the codename 1492 or Amazon X and conducts research into secret projects in areas like innovative health technologies and cancer (Hale 2018). According to media reports, Amazon is also working with the Fred Hutchinson Cancer Research Center, which focuses on research projects for the early detection and treatment of cancers, to apply ML in cancer prevention and treatment, although few other details are publicly available about this collaboration (Kim and Farr 2018, 2017). It is publicly known, however, that Amazon has a seat on the Board of Trustees[91] of the Fred Hutchinson Cancer

91 The Board of Trustees of the Fred Hutchinson Cancer Research Center also includes leading executives from other tech giants, including Microsoft CEO Satya Nadella (Fred Hutch, July 11, 2016).

Research Center and that it provides the organization with support through funding for projects relating to COVID-19 and other topics (Fred Hutch April 17, 2020, July 9, 2019).

MICROSOFT Research conducts extensive research activities in the fields of intelligence (including AI and others, see section ➔3.1), systems (such as on data platforms and analytics, see section ➔3.4.1), and theory, as well as in other scientific fields such as medical, health, and genomics (Microsoft Research 2021c). The latter area includes numerous projects and publications on the application of novel computational tools and analytical techniques that it says will help transform healthcare and empower people to lead healthier lives. Research topics include COVID-19, deep learning toolkits and biomedical natural language processing (NLP) (Microsoft Research 2021b). Microsoft's Research Asia Lab launched a website in April 2020 called COVID Insights that serves as a portal for current analyses and studies relating to COVID-19 (Meskó et al. 2020: 31).

Information about Microsoft's AI for Good Initiative and Project Hanover can be found in section ➔3.1, information on Microsoft Genomics can be found in section ➔3.4.1 and information about Microsoft AI for Health and Microsoft Healthcare NExT can be found in section ➔3.4.9.

MICROSOFT

Microsoft Research

Microsoft AI for Good Initiative

Project Hanover

Microsoft Genomics

Microsoft AI for Health

Microsoft Healthcare NExT

IBM has established the AI Horizons Network, a global network of scientists, to further develop the use of AI in research projects and experiments as part of a long-term partnership with the University of Stuttgart since 2020, for example (IBM April 28, 2020). The projects address global challenges in a variety of fields, including health and the environment (IBM 2021a).

IBM

AI Horizons Network

INTEL and Google Cloud have joined the U.S. National Institute of Health's (NIH) All of Us Research Program, which is collecting biomedical data from study participants in the U.S. to explore relationships between various factors such as lifestyle, socioeconomic status and environment and health. The stated goal of the project is to reduce healthcare disparities and improve health outcomes for under-represented groups of people in the United States (Healthcare Global 2021; All of Us Research Hub 2021).

Information about Intel's research projects with the University of California San Francisco (UCSF) and the University of Pennsylvania can be found in section ➔3.1.

INTEL

All of Us Research Program

Further research projects with universities

NVIDIA's graphics processing units (GPU) are integral hardware components in computers used for sophisticated research projects worldwide, regardless of explicit partnerships with the tech giant (Meskó et al. 2020: 45). Second only to Intel, which has 62 % market share, NVIDIA is the world's second largest GPU company, with a 20 % market share in the third quarter of 2021 (Dow 2021). Researchers at the Mayo Clinic in the U.S., for example, use NVIDIA's GPU to infer the genetic information of brain tumors without having to perform a biopsy (Halabi 2017).

NVIDIA

NVIDIA GPU

NVIDIA Clara Imaging & Clara Parabricks

NVIDIA Inception Program

NVIDIA Clara[92] is a platform and application framework for healthcare researchers that supports accelerated computing and AI in imaging and genomics, in addition to other areas. The aim is to create innovation and advance precision medicine (NVIDIA 2021d). Infervision, a Beijing-based startup and member of the NVIDIA Inception network, used NVIDIA graphics processing units (GPU) and NVIDIA Clara Imaging and over 400,000 lung X-rays to train an AI algorithm (Simonite 2019; Powell 2018). That AI application has been incorporated into InferRead CT Pneumonia, which is used to assist physicians in detecting lung cancer. During the COVID-19 pandemic, its application in Wuhan, China, has helped and continues to help with the early detection of COVID-19-related disease through lung screenings (Alarcon 2020). NVIDIA's Clara Parabricks has been deployed in numerous genome analytic research projects – to develop a vaccine against COVID-19, for example, as well as in other projects including the development of robots for disinfection and contactless temperature measurement of potentially infected individuals (Meskó et al. 2020: 46-47).

PHILIPS

Digital Twin Technology: HeartModel

Mind Control

PHILIPS has used AI-based "digital twin" technology to develop a digital twin of the human heart (HeartModel). Digital twins are virtual models of systems that are updated dynamically and are "connected" to their physical counterparts. This technology will help analyze systems in real time, prevent problems and test innovations in virtual environments before they are introduced into everyday care (Philips 2018b).

In one research project together with neurotechnology and design companies, Philips' Hue Lighting, SmartTV and Lifeline Medical Alert products will be linked together so that patients with neurodegenerative conditions can control them using "mind control." The aim is to give patients the ability to overcome mobility limitations by using brain commands. A tablet app will translate these commands and connect them with other devices. Users can use the Emotiv headset to send commands either by way of mind commands or muscle commands (Philips n. d. a).

SAP

Brain Age Project

SAP Connected Health Platform

SAP's Machine Learning Research is conducting an AI research project, the Brain Age Project, in cooperation with Ludwig Maximilian University (LMU) in Munich that aims to jointly develop new methods of supporting doctors and patients with innovative, ML-based treatment approaches (Haegerich 2018).[93]

SAP is also pursuing the goal of optimizing healthcare processes and, to that end, conducted research into an application in cooperation with the Helios Clinic hospital in Berlin that attempts to predict waiting times for emergency admissions (SAP News Center Nov. 21, 2018).

For more information about SAP Connected Health Platform (formerly SAP Foundation for Health), see section →3.3.

92 NVIDIA Clara Parabricks provides off-the-shelf software for primary, secondary and tertiary analyses of genomic data. It has applications in population genomics, cancer genomics and RNA sequencing projects (NVIDIA 2021c). NVIDIA's Clara Imaging is an AI-based application framework for medical imaging. The target group includes data scientists and researchers who create complex datasets and develop collaborative methods for training reliable AI models and end-to-end software for scalable and modular AI applications (NVIDIA 2021b).

93 The Brain Age Project used 1,000 anonymized, publicly available MRI scans of healthy subjects to train an ML model designed to identify anatomical signs of aging in the brain (Haegerich 2018).

SIEMENS Healthineers maintains a global research and development team with a focus on patient-centered and demand-driven healthcare in the clinic. The areas of work and stated goals include the optimization of working processes in treatment, simplified data preparation and optimized diagnosis and treatment approaches (Siemens Healthineers 2021n). Like Philips, Siemens is involved in the research and development of AI-based digital twin technology (Siemens 2021b).

SIEMENS

Siemens Healthineers

Diagnosis and treatment approaches

Digital Twin Technology

SAMSUNG's My BP Lab is both an app (➔3.2) and a study resulting from a collaboration between Samsung and the University of California San Francisco (UCSF).[94] Users of the app are invited to participate in a three-week study at UCSF. Participants are asked to monitor their stress levels and subjective and emotional well-being, provide daily behavioral information (sleep, exercise and diet), and record their blood pressure throughout the day using a smartphone. The researchers are hoping to use the app to collect and analyze a comprehensive data set on measured stress, subjective well-being and blood pressure (Samsung, Feb. 26, 2018; UCSF Feb. 25, 2018). The study and the use of the app is intended to improve the measurement of blood pressure through smartphones and wearables (My BP Lab 2021; Banks 2020).

Explanations of Samsung's research projects in the context of the Samsung Gear VR headset can be found in section ➔3.2.

SAMSUNG

My BP Lab

TENCENT is entering the research scene with three major AI-related labs designed to support medical AI-based research: Tencent Medical AI Lab, Tencent YouTu Lab and Tencent AI Lab. The first is focused on research into new digital biomarkers for detecting and predicting diseases; Tencent YouTu Lab explores AI-based medical imaging (see Tencent Miying, section ➔3.3) and Tencent AI Lab is focused on the overall process of medical care, providing solutions in areas such as AI-based diagnostics and treatment (Tencent 2019).

TENCENT

Tencent Medical AI Lab

Tencent YouTu Lab

Tencent AI Lab

94 Samsung and the University of California San Francisco (UCSF) first partnered in 2014 to develop new sensors, algorithms and health technologies in preventative health. The partners set up a lab for the purpose – the UCSF-Samsung Digital Health Innovation Lab. Samsung is actively promoting both the patenting of technologies developed at the Innovation Lab and the incorporation of developments emanating from UCSF's Center for Digital Health Innovation (CDHI) into the Innovation Lab for further research and enhancement with Samsung's expertise (Pai 2014).

3.5.1 FEATURED EXAMPLE: RARE DISEASES

"In the European Union, a disease is considered to be rare when it affects no more than five in 10 000 people. Since there are more than 6 000 different rare diseases, the total number of people affected is high despite the rarity of the individual diseases"[95] (Federal Ministry of Health 2021c).

Rare diseases, also called orphan diseases, are chronic and possibly life-threatening diseases that are often genetically linked (Kaplan et al. 2013: 148), although there are also rare infectious diseases. In most cases, there is uncertainty about the exact cause(s). Rare diseases are often discovered at birth or during childhood, but the largest share is discovered in adulthood (Orphanet 2012). Around 30 % of children who suffer from rare diseases die (de Vrueh et al. 2013: 11).

One major challenge is the lack of reliable epidemiological data (de Vrueh et al. 2013: 11). As a result, there is very little general knowledge about rare diseases, so diagnoses are often made too late and after lengthy and burdensome paths through the healthcare system, or not at all. The number of drugs[96] and specialists available around the world is also limited. Still, there are efforts to accelerate the development of medications for rare diseases, "orphan drugs," by shortening testing and approval periods, for example[97] (de Vrueh et al. 2013: 18–22).

ALIBABA
Alibaba
Ali Health
Global Drug Information Platform for Rare Diseases

ALIBABA Ali Health, in partnership with Bo'ao Winhealth Rare Disease Medical Center, launched the Global Drug Information Platform for Rare Diseases in September 2021. The information platform includes a health service network that is available both online and offline. The platform addresses the problem of the lack of availability or affordability of innovative treatments for rare diseases. Ali Health's technologies, including AI and cloud computing, are expected to augment the platform (Winhealth Pharma 2021).

HUAWEI
Collaboration with Philips

HUAWEI and Philips are collaborating in the area of cloud-based AI to use big data to infer relationships between specific groups of people, geographic areas and rare diseases (Huawei 2021).

95 WHO's definition: "In the EU, a disease is considered to be rare when the number of people affected is less than 5 per 10 000. There are between 5 000 and 8 000 rare diseases, most of them with a genetic basis" (Kaplan et al. 2013: 148).

96 In the clinical development phases of these drugs, challenges include an insufficient number of patients, a lack of validated clinical points of reference (surrogate endpoints, biomarkers) and ethical issues (e. g., use of placebos) (de Vrueh et al. 2013: 22).

97 In Germany, however, under the German Medicines Market Reorganization Act (AMNOG), orphan drug status does not lead to shorter approval times (VfA 2018).

IBM

Collaboration with Graticule

IBM is seeking to close the data-to-study gap in rare diseases in a partnership with Graticule. To achieve this, data from IBM MarketScan Research Databases and IBM Explorys Therapeutic Datasets will be used to accelerate research and solve the problem of difficulties in recruitment for clinical trials. IBM and Graticule hope to gain a better understanding of disease progression by examining the natural history, comparing the effectiveness and safety of medical devices in everyday care and learning new insights about new drugs that are not yet approved for reimbursement (Watson Health 2021).

INTEL

Collaboration with Dell Technologies and TGen

INTEL is collaborating with Dell Technologies and the non-profit Translation Genomics Research Institute (TGen) in an effort to detect, treat and help prevent rare diseases faster. As part of the project, the partners built a high-performance computing (HPC) infrastructure in 2012 designed for the life sciences sector. Goals included improving genomic pipelines to rapidly obtain results and identify treatment options within the clinically relevant timeframes. At the same time, an emphasis was placed on lowering costs and protecting private data (Intel, n. d.).

MICROSOFT

Collaboration with Shire and EURORDIS

Global Commission to End the Diagnostic Odyssey for Children with a Rare Disease

MICROSOFT partnered in 2018 with the pharmaceutical company Shire and the NGO EURORDIS to accelerate rare disease diagnostics, incorporating technologies such as ML, intelligent triage and virtual consultations. A blockchain-based patient registry was also created as part of the project. Together, they created the multidisciplinary Global Commission to End the Diagnostic Odyssey for Children with a Rare Disease, with Microsoft's Chief Medical Officer (CMO) of Worldwide Health, Simon Kos, among others, at the helm (Fernández 2018; Global Commission on Rare Disease 2019). As part of its work with the Commission, Microsoft in 2021 launched the RareNavigator, a tool that gathers customized information using the Azure Health Bot – both from caregivers and families with a child with a rare disease. The tool is limited to a pilot project in the San Diego area, but there are plans to expand it to sites in Ireland and Australia (Meade et al. 2021).

NVIDIA

NVIDIA Inception Virtual Accelerator Program, Kooperation i. a. with Recursion

NVIDIA is tapping deep learning to advance drug discovery for rare diseases. As part of its NVIDIA Inception Virtual Accelerator Program, NVIDIA is collaborating with the startup Recursion to analyze image date from (pathologically altered) cells. Recusion's goal is to discover 100 new treatment approaches by 2025. In pursuit of that goal, robotic arms are conducting around 100,000 experiments each week, resulting in the creation of about 2 million high-resolution biological images (Salian 2019).

SAMSUNG

Bioepsis

SAMSUNG Bioepsis is analyzing data from patients with the rare blood disorder paroxysmal nocturnal hemoglobinuria (PNH) who are receiving treatment with a biosimilar (SB12) from Samsung in a multicenter Phase 3 study (Pulse 2021).

TENCENT

Collaboration with RareStone

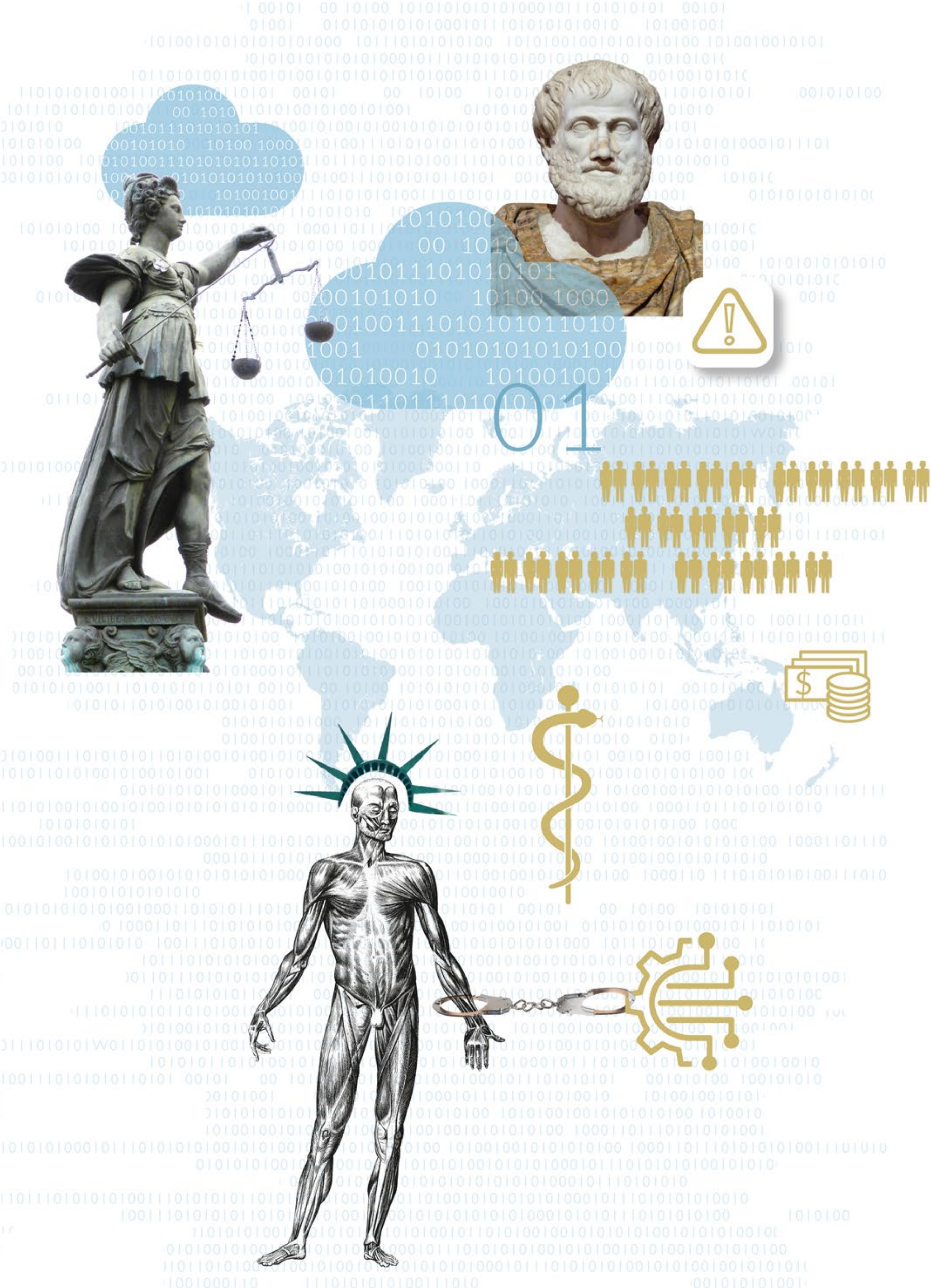
TENCENT is collaborating with RareStone to build an ecosystem focused on rare disease patients in China. The partnership aims to promote education, social awareness and improve accessibility to information and services relating to rare diseases. Innovative digital solutions are to be used for this purpose (Global Genes 2021).

3.5.2 SUMMARY

The tech giants are extremely active in health-related science, research and development. Their activities, often pursued in collaboration with academic institutions or healthcare companies, benefit from their ability to collect, refine and process enormously large data sets from a variety of sources within and outside the healthcare system. The focus is on developing innovative products and services that either target specific diseases or diagnostic tools or develop and deploy cloud technologies and AI models to support studies by other actors in the scientific system. The tech giants are thus gradually becoming indispensable and, as such, powerful participants in the health-related sciences – with all the advantages and disadvantages that come along with that.

In addition, the increased integration of data collected outside of controlled study environments by patients and users themselves means that the lines between research, everyday care and the lifestyle sector are increasingly blurring. The large amounts of data and their AI-supported analysis also enable research on rare diseases to be advanced in many ways.

The ethical issues that arise in connection with the activities of the tech giants in science, research and development are discussed in chapter ➔4.



4 ETHICAL ANALYSIS

4.1 INTRODUCTION

Health technologies affect fundamental values such as life, health, liberty and justice. They are therefore of broad ethical significance, in the sense that they can both promote and endanger the realization of these values. For example, a clinical decision support system that uses AI could help improve the evidence basis for a treatment decision in a case of cancer, and thus significantly prolong the patient's life. However, if used unreflectively or with bad underlying data, the same tool could also lead to treatment decisions that endanger the patient's life (Braun et al. 2021). At the global level, technology could on the one hand help people in remote regions obtain healthcare services, and thus promote equity of access; on the other hand, it could also widen the so-called digital divide (→4.3.1), and thus represent a step backward from the perspective of distributive justice (Ibrahim et al. 2021; Topol 2019; Marckmann 2016).

The challenge of exploiting the opportunities of technologies while avoiding the risks as far as possible has long been reflected and systematically addressed in technology assessment. Such evaluations also consider technology's fundamental role in shaping aspects of individual and social life. In this context, four distinct functions of ethics can be seen as framing the nuanced discussion and evaluation of technologies: 1) legitimation, 2) conceptualization, 3) evaluation, and 4) justification of norms (Woopen and Mertz 2014).

LEGITIMATION refers to the ethical obligation to identify any negative consequences associated with a given technology at an early stage, while also ascertaining and advancing the technology's positive effects (Woopen and Mertz 2014: 42).

CONCEPTUALIZATION describes the necessity of ethically justifying the process used to evaluate the technology. This evaluation will inevitably reflect societal attitudes, which means that values such as health, life, well-being, safety, justice and the prudent use of scarce resources may be conceptualized and weighed differently at different times and places. The conceptualization function also entails the claim that those affected by a given technology should participate in and help shape the technology assessment process, so as to reflect a broad spectrum of different views and "counteract the much-deplored loss of democracy" (Woopen and Mertz 2014: 43).

EVALUATION, in its essence, refers to the idea that an ethically informed assessment of what constitutes potential harm or potential benefit must go beyond a mere gathering of facts. Rather, these facts must be evaluated in terms of their ethical relevance. This demands expertise in the field of ethics, including the ability to "reconstruct, classify and evaluate normative arguments and frameworks, and to proceed in a manner consistent with ethical theory" (ibid.: 45).

JUSTIFICATION OF NORMS, finally, consists in the fact that the process of creating technology standards should take place for ethical reasons as well, and not solely for purely technical or bureaucratic reasons, or for the advantage of the standardizers themselves (ibid.: 45). A distinction must initially be made between legal, economic and social grounds and ethical factors, even if the former can also be ethically relevant. When technologies are of global significance, a cross-cultural dimension should be taken into account (ibid.: 46).

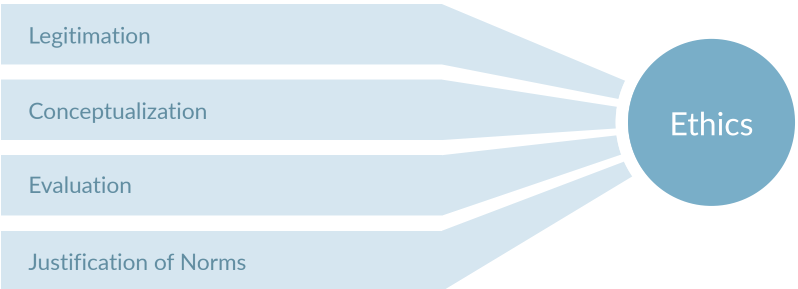


FIGURE 13:
Functions of ethics
Source: Authors. Data: Woopen and Mertz 2014, Bertelsmann Stiftung

The goal of the ethical analysis is to point out and describe the complexity of the technological transformation being led by the tech giants in the healthcare sector, to promote discussion about it, and to develop recommendations for action that can promote desirable innovations and avert potentially negative consequences. This corresponds to an ethics-by-design approach, a strategy that is currently becoming more prominent particularly in the field of AI development. Under this framework, development and design teams reflect upon ethical factors as an integral element of their entire process, both before and during the technology's deployment, rather than considering these factors only after development has been completed. One element of this concept is the initial use of a participatory process to identify and eliminate potential problem areas (Brey and Brandt 2020).

4.2
ETHICAL VALUES AND PRINCIPLES

The following ethical analysis of the tech giants' health-related activities is based on eight values and principles (Data Ethics Commission 2019) that refer to the fundamental rights and freedoms enshrined in documents including the Charter of Fundamental Rights of the European Union (CFR),[98] the European Convention on Human Rights (ECHR),[99] the Universal Declaration of Human Rights (UDHR),[100] and, for example, the Basic Law of the Federal Republic of Germany (GG).[101,102] These eight values and principles are:

» Human Dignity
» Freedom and Self-Determination
» Health
» Privacy
» Security
» Justice and Solidarity
» Sustainability
» Democracy

4.2.1
HUMAN DIGNITY

"Human dignity is a principle that presupposes the unconditional value of every human being, prohibiting such practices as the total digital monitoring of the individual or his or her humiliation through deception, manipulation or exclusion" *(Data Ethics Commission 2019: 14).*

Drawing on the Basic Law of the Federal Republic of Germany (GG), the Charter of Fundamental Rights of the European Union (CFR), the European Convention on Human Rights (ECHR) and the United Nations Declaration on Human Rights (UDHR), human dignity is considered as being the first, most fundamental principle. Although there is no universally valid, ubiquitously accepted definition of human dignity, there is widespread agreement on a core aspect of the term: that human beings, in themselves, possess an unconditioned value that is not linked to any other

98 Charter of Fundamental Rights of the European Union, OJ 2010/C 83/02.

99 Convention for the Protection of Human Rights and Fundamental Freedoms of 4 November 1950.

100 Universal Declaration of Human Rights, of December 10, 1948, UN A/RES/217-A-(III).

101 Basic Law for the Federal Republic of Germany (GG), of May 23 1949, BGBI. 1; as amended on 29 September 2020, BGBI. I, 2048.

102 Given the scope of this work, it is impossible to provide a comprehensive account here of the many different facets and ways of conceptualizing individual values and the trade-offs between them. However, the study identifies the authors' standpoint on these subjects, and contains references to related literature.

specific capacity or characteristic, and does not first have to be acquired by any action, deed or fulfilment of condition.

Human dignity entails a social claim to value and respect that prohibits actions making persons into a "mere object" of state action, or which subject them to treatment that fundamentally fails to invariably recognize them as autonomous individuals.[103] On the one hand, this obliges the state to respect its citizens' human dignity and fundamental rights. On the other, the state, by means of regulation, must also protect its citizens against violations of these rights by third parties.

As early as 1486, Giovanni Pico della Mirandola referenced the idea of human dignity in his Oratio de Hominis Dignitate,[104] in which he placed particular emphasis on the principle of freedom: "'The nature of all other creatures is defined and restricted within laws which We have laid down; you, by contrast, impeded by no other restrictions, may, by your own free will, to whose custody We have assigned you, trace for yourself the lineaments of your own nature'" (Pico della Mirandola 1956).[105]

In Article I of the Universal Declaration of Human Rights, the United Nations also says that "all human beings are born free and equal in dignity and rights (...)" (UN 1948), thus indicating that human dignity is intertwined with human freedom. The human being is therefore entitled to respect solely because he is human;[106] he is not subject to any classification.

According to this understanding, people can utilize technology in order to "realis[e] human ideas and objectives more effectively and rapidly and with fewer errors" (Data Ethics Commission 2019: 43). However: "At the same time, the notion that technology should serve humans rather than humans being subservient to technology can be taken as incontrovertible fact" (ibid: 14).

4.2.2
FREEDOM AND SELF-DETERMINATION

"Self-determination is a fundamental expression of freedom, and encompasses the notion of informational self-determination. The term 'digital self-determination' can be used to express the idea of a human being as a self-determined player in a data society" *(Data Ethics Commission 2019: 14).*

Freedom and self-determination are fundamentally intertwined. There are a variety of different definitions for each, all subject to a rich array of interpretations. In the case of the first concept, a distinction can be made between positive freedom – according to which individuals develop and

103 See, for example, the decisions of the German Constitutional Court, BVerfGE 27, 1, 6; 45, 187, 228; 109, 133, 149 f.; 117, 71, 89.

104 English translation: "Oration on the Dignity of Man".

105 Translated by A. Robert Caponigri in Pico della Mirandola (1956).

106 "(...) the value which is inherent in every human being and which does not need to be acquired (...)" (Data Ethics Commission 2019: 43).

pursue their own self-chosen goals – and negative freedom, referring to the absence of external obstacles (Carter 2016; Berlin 2002).

Self-determination is understood here as "the possibility of realizing one's own plans of actions and decisions on action. [This] is a fundamental anthropological idea whose realization depends on empirical circumstances" (German Ethics Council 2013: 111). It is human beings' autonomy that makes this possible. This refers to "the fundamental ability of humans to engage in sensible reasoning, exchange reasons for actions with other individuals, and make responsible decisions on their own initiative. This ability marks humans as moral beings" (ibid).

In the digital space, the focus is on informational self-determination and digital self-determination. The constitutionally recognized principle of informational self-determination essentially refers to "the authority conferred on the individual to, in principle, decide themselves on the disclosure and use of their personal data."[107] For example, the state is prohibited from collecting or using data unless it has a legal basis for doing so that strikes an appropriate balance between the right to informational self-determination and the interests of the state. Moreover, the state must also ensure that its regulations sufficiently balance the interests of the private actors involved – for example, those of the data subjects and the companies that use their data. Europe-wide Regulation of this type is found primarily in the General Data Protection Regulation (GDPR).[108]

Digital self-determination refers to an actor who, on the basis of sufficient information about differing possibilities, makes a voluntary decision based on his or her own personal values regarding how to handle his or her own data, the digital exchange of information, and the use of digital products or applications, and then acts accordingly (Mertz et al. 2016). "Digital self-determination always goes hand in hand with digital accountability" (Data Ethics Commission 2019: 44).

4.2.3 HEALTH

***"Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity"** (WHO 2006: 1).*

With this sentence, which the World Health Organization (WHO) wrote into the preamble of its constitution in 1946, the organization emphasized its biopsychosocial conception of health. It regards the possession of the best possible state of health as a fundamental right. In the U.N. Social Covenant,[109] this was included as "the right of everyone to the enjoyment of the highest attainable standard of physical and mental health." This is not meant to imply that people can be in a completely optimal state of health at all times. Rather, the goal is to ensure that the standard

107 See, for example, the decision of the German Constitutional Court, BVerfGE 65, 1 ff.: "Under the modern conditions of data processing, the free development of the personality presupposes that the individual is protected against the unlimited collection, storage, use and disclosure of his or her personal data."

108 See above footnote 3.

109 International Covenant on Economic, Social and Cultural Rights of 16 December 1966, UN A/RES/2200-A-(XXI).

of measurement being used relates to the achievement of the best possible level of individual and public health in every case. This goal is to be realized through appropriate access to good health-care and the creation of health-promoting conditions, while also taking the social determinants of health into account (WHO 2008; Krennerich 2020; WHO 2021c; Wulf 2016; WHO 2004). The WHO emphasizes that all people have the same right to health, and that this is essential for the attain-ment of peace and security[110] (WHO 2006). The right to health is also enshrined in Article 35 of the EU Charter of Fundamental Rights.[111]

4.2.4 PRIVACY

"The right to privacy is intended to preserve an individual's freedom and the integrity of his or her personal identity. Potential threats to privacy include the wholesale collection and evaluation of data about even the most intimate of topics" *(Data Ethics Commission 2019: 14).*

Within the philosophical discourse, there is no uniform definition for the concept of privacy. Aristotle uses the term to distinguish between a public, political level (polis) and a private, familial or domestic level (oikos) (DeCew 2018). This distinction implies that different entities have different responsibilities with regard to setting rules: 1) the state in the public sphere and 2) the individual in the private sphere (ibid.). According to the conception of privacy stemming from the so-called Age of Enlightenment still valid today, every person simply has the right "to be let alone" (Warren and Brandeis 1890).[112]

The principle of privacy is intertwined with human dignity and self-determination, including informational self-determination. Thus, everyone has the right to protect their own privacy even within the public sphere (DeCew 2018; Data Ethics Commission 2019)[113] – and, in so doing, the right to lead a self-determined life. This also includes personal control over "who may access which personal information relating to him or her, and when and for what purpose they may do so". The state protects privacy through "legislative measures to regulate the responsible use of personal data" (Data Ethics Commission 2019: 45).

110 "The enjoyment of the highest attainable standard of health is one of the fundamental rights of every human being without distinction of race, religion, political belief, economic or social condition. The health of all peoples is fundamental to the attainment of peace and security and is dependent upon the fullest co-operation of individuals and states" (WHO 2006: 1).

111 See Article 35 of the Charter of Fundamental Rights of the European Union, OJ 2010/C 83/02: "Everyone has the right of access to preventive health care and the right to benefit from medical treatment under the conditions established by national laws and practices. A high level of human health protection shall be ensured in the definition and implementation of all Union policies and activities."

112 See Warren and Brandeis (1890: 193).

113 See also the German Constitutional Court's decisions, VerfGE 115, 11, 183 ff.; 101, 361, 383; 99, 185, 193; 65, 1 ff.

4.2.5
SECURITY

***"The principle of security relates not only to the physical and emotional safety of humans but also to environmental protection, and as such involves the preservation of vitally important assets. Guaranteeing security entails compliance with stringent requirements, e. g. in relation to human / machine interaction or system resilience to attacks and misuse"** (Data Ethics Commission 2019: 14).*

In its Universal Declaration of Human Rights, the United Nations included the right to security: "Everyone has the right to life, liberty and security of person."[114] This also includes the right to safe products, safe working and living conditions, and a safe living environment, for example through the government's creation of generally binding safety standards. The societal need for protection from physical, social and emotional harm is also served by an enforceable claim for compensation for harm caused by unsafe products, for example (Mohan 2003).

The principle of security is relevant at a number of different levels. For example, it encompasses the protection of physical and mental health or integrity (e. g., in human-machine interactions), as well as protection of the environment and public safety. In addition, security includes the protection of privacy, as this can relate to the collection and use of data, among other concerns (Data Ethics Commission 2019: 45).

4.2.6
JUSTICE AND SOLIDARITY

***"In view of the vast amounts of power being accumulated using data and technologies, and the new threats of exclusion and discrimination, the safeguarding of equitable access and distributive justice is an urgent task. Digitalisation should foster participation in society and thereby promote social cohesion"** (Data Ethics Commission 2019: 15).*

Ideas about justice serve to determine the "basic coordinates of a morally and legally grounded structure of relationships" (German Ethics Council 2017b: 219). As concepts of justice have evolved since Aristotle's time, different thinkers have come to distinguish between different types of justice. This includes distributive justice, which relates to the distribution of scarce resources according to a specified external standard. Another variety is compensatory justice, which mandates that damages caused by a criminal act or a breach of contract, for example, must be compensated for on the basis of their magnitude, and thus independently of any external standard. Finally, the list also

114 Art. 3 Universal Declaration of Human Rights, see above, footnote 100.

includes procedural justice, stating that just conditions arise because of and through just procedures.

This inventory is rough at best, and a variety of further nuances are evident in each case. Explicit conceptions of social justice emerged beginning with industrialization in the 19th century. They differ, for example, in whether “justice” refers to something attained or to a demand; to equality of opportunity (for instance under a capability approach)[115] or equality of outcome; or to the status of individuals or the status of groups (along with their related claims). Although there may be consensus that social justice is something good and desirable, it may in any given case involve mutually incompatible and mutually exclusive ideas. However, these ideas have a common goal:

“As a normative principle of social relations, justice requires that the arbitrary privileges of individuals or certain groups be overcome by determining what is appropriate to each in a rational manner, that each person be given equal consideration in the actions of others, and that differences in treatment require a consensual justification” (German Ethics Council 2017b: 222).

In legal terms, the principle of equality enshrined in Articles 20 and 23 of the Charter of Fundamental Rights of the European Union,[116] is of key importance. The state is, simply stated, generally prohibited from treating substantially equal entities unequally –, unless this is based on sufficiently weighty factual grounds, and is done so in reasonable proportion to the disadvantages suffered by the individual.[117] In addition, there are absolute prohibitions of unequal treatment based on enumerated characteristics.

Justice and solidarity are closely linked, but are not coincident. Solidarity has numerous facets, ranging from the sense of belonging, to the creation of a group that stands up for a common goal, to mutual support under conditions of scarcity (Woopen 2008). Most conceptions of solidarity share a number of key elements: “The concept of solidarity denotes prosocial behaviors, practices and dispositions, as well as institutional, political and contractual regulations, the purpose of which is to assist others” (German Ethics Council 2017a: 25).

Most authors also agree that to be able to speak of solidarity, the element of prosociality must be supplemented by corresponding actions or the assumption of costs – understood in a broad sense – such as those of a financial, social, emotional or temporal nature (German Ethics Council 2017a: 25). “Solidarity is frequently understood as complimentary to – and often subsidiary to – the concept of justice” (ibid.). Underlying solidarity is the fact that “it regularly emerges against the background of a group’s common goals, in the face of a common challenge or from a shared idea of the good life within a mutually supportive community”, as in the case of the German welfare state (ibid.: 25).

115 See, for example, Sen (1979), Sen (2009), Daniels (1990), Nussbaum (1998), Nussbaum (2015).

116 See above footnote 98.

117 See especially BVerfGE 55, 72, 88.

Thus, solidarity is not to be regarded as neutral, but can rather be seen as "standing between the just and the good" (German Ethics Council 2017a: 228) or as "just compassion" or "compassionate justice" (Woopen 2008). In the area of digital healthcare, technology can help strengthen solidarity, but can also undermine and weaken it (Data Ethics Commission 2019: 47).

4.2.7 SUSTAINABILITY

"Digital developments also serve sustainable development. Digital technologies should contribute toward achieving economic, ecological and social sustainability goals" *(Data Ethics Commission 2019: 15).*

There is no uniform understanding of the concept of sustainability. The most widely used definition comes from the 1987 Report of the World Commission on Environment and Development 'Our Common Future': "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (UN 1987: 37).

As the concept of sustainability has developed over time, various models[118] have emerged that all include the three dimensions of social, ecological, and economic sustainability (Pufé 2014: 17–18). These are also reflected in the United Nations' 17 Sustainable Development Goals (SDGs),[119] which seek to further sustainable development at the social, environmental, and economic levels in all countries by 2030 (UN 2015; Data Ethics Commission 2019: 47). Tech-based innovations can contribute to realizing sustainable development goals, for example by making resource use more efficient (Data Ethics Commission 2019: 47). At the same time, they also demand the utilization of immense quantities of resources, for instance through the perpetually rising demand for energy, which is unsustainable and may be associated with negative impacts on the environment (van Wynsberghe 2021; WHO 2021a; Data Ethics Commission 2019).

Sustainability goals are closely related to the demands of justice. This includes intra- and intergenerational justice (Pufé 2014: 20). The former concerns aspects related to the equitable global distribution of growth and prosperity and the use of resources, especially against the background of a gap between the Global South and the Global North (ibid.: 16). Intergenerational justice touches on issues of global responsibility for future generations (Data Ethics Commission 2019: 47). In Germany, for example, the protection of the natural foundations of life is also constitutionally enshrined in Article 20a of the Basic Law.

118 See: Three pillar model, the overlapping-circles model and the sustainability triad (Pufé 2014: 17–18).

119 The Sustainable Development Goals include e. g. "good health and well-being" (SDG 3), "responsible consumption and production" (SDG 12), and "climate action" (SDG 13) (UN 2015).

4.2.8 DEMOCRACY

"Digital technologies are of systemic relevance to the flourishing of democracy. They make it possible to shape new forms of political participation, but they also foster the emergence of threats such as manipulation and radicalization" *(Data Ethics Commission 2019: 15).*

Etymologically speaking, democracy is rule by the people, with the term containing elements of the Greek words *demos* (people) and *kratos* (rule or power) (Kuyper 2015; Keane 2009). In short, democracy is a political order in which citizens govern themselves through a decision-making process in which each has more or less the same rights (Kuyper 2015).[120]

Digital technologies are "in a complex manner systemically relevant for the development of fundamental rights, (...) for democracy, (...) [and] for an open societal debate" (Data Ethics Commission 2019: 46). Education and training also play a central role in "safeguarding the free democratic basic order," in which the democratic principles of the state are guaranteed and the fundamental rights enshrined in the constitution are protected. Among their other effects, these institutions impart technical skills and thereby create "the participation of citizens in the shaping of society – a process that is of critical and fundamental importance for democracy" (ibid.).

120 "(...) a political practice in which individuals govern themselves through some form of equitable decision-making process" (Kuyper 2015).

4.3
TRANSFORMATION IN HEALTHCARE AND THE HEALTHCARE SYSTEM

Observers have long placed high hopes in the prospect of a fundamental, digitalization-driven transformation of the healthcare sector. As often envisioned, this would entail the collection and processing of vast amounts of data generated by a wide range of sensors gathering data in, on and outside the human body, with analysis supported by the use of artificial intelligence. The trend is seen as an opportunity for the widespread introduction of patient-centered precision medicine (Topol 2015), although potential problems of many different kinds are also being discussed (IBC 2017; German Ethics Council 2018). This transformation has today progressed to different degrees in different countries (Thiel et al. 2018), and is dynamically reshaping the industry, shifting boundaries and even dissolving intersectoral borders. In the following sections, we highlight a number of these changes, and discuss them on the basis of the values and principles outlined above.

These developments have not been driven exclusively by tech giants, as many other sectoral actors have also had a significant influence. However, the tech giants have played a dominant role. This is due to their disproportionately greater technical capacities and competencies, as well as their financial and thus also personnel resources. The sum of these advantages allows them to occupy a monopoly-like position. As described in chapter →3, the large companies offer a wide range of health-related products and applications for patients and users as well as for healthcare professionals. They are also active in the science, research and development fields, and provide additional support for such activities through cooperative ventures and partnerships. In some cases – although these remain only a few – they are even developing and establishing healthcare structures such as hospitals and integrated care services, and operating their own health insurance programs.

Ultimately, tech giants are advancing digital healthcare, and have the potential to become indispensable actors within the healthcare sector – making it dependent on them in at least some areas. In general, European tech giants have tended to focus on producing specific devices and applications for clinical areas or individual conditions, while U.S. tech giants have accumulated their power to shape individual and social life, including the market, by gathering huge amounts of data from different areas of life, and then basing business models and projects on this resource. For their part, Chinese companies also collect huge amounts of data, but their products and applications are additionally used to assess and control users.

Strengthening data-based prediction, prevention and precision medicine

→ The collection of large amounts of health-related data from different areas of life and real-time data processing by AI systems is leading to a shift in focus in the medical field

→ Sometimes referred to as P4 medicine (preventive, predictive, personalized and participatory); individualized, personalized, or stratified medicine; disease interception; or precision medicine

Multidimensional change in competencies of healthcare professionals

→ A need to constantly update health profession skill sets in the provision and organization of healthcare services

→ Change in health professions' required skills and self-conception

→ Emergence of new health professions

→ Redesign of education, training and continuing education programs

Monopolization and dissolution of sectoral boundaries due to digital healthcare

→ Traditionally separate sectors become less distinct and begin to merge due to the digital availability of health data in a highly digitally networked system (integration of outpatient, inpatient and rehabilitative sectors; public and private sectors)

→ Great financial, human and technological resource advantages give tech giants a lead in collecting and processing huge amounts of data, and in the (further) development of AI systems

Linking everyday care and research to a learning healthcare system

→ Data from everyday healthcare is generated, combined and processed for research purposes

→ Research findings are systematically introduced into everyday care

→ Everyday care and research are linked in a regulated cycle of knowledge generation and knowledge application

FIGURE 14: **Transformation in healthcare and the healthcare system**
Source: Authors, Bertelsmann Stiftung

4.3.1
STRENGTHENING DATA-BASED PREDICTION, PREVENTION AND PRECISION MEDICINE

The multifaceted debates over the future of digitalized healthcare have produced numerous visions for the future, ranging from incremental transformations to the creative destruction of current medical practices and structures (Topol 2015; Thuemmler and Bai 2017; Topol 2013). Many observers agree that one major advance in particular – a shift in the healthcare field's focus from therapeutic care to prevention – is likely to have a positive impact on both individual and public health. This development is being facilitated by the accumulation of large amounts of health-related data from different areas of everyday life, often collected by users and patients themselves, paired with the real-time processing of this information by AI systems. This represents an important, if not yet sufficient step in the transformation toward a "no longer reactive, but rather preventive and personalized medicine, which would be made possible by the precise knowledge of individual risk factors, subjective states and the possible side effects of the medications administered" (Research Services of the German Bundestag 2013: 2; Friele et al. 2020).

A variety of different terms are used to refer to this new type of medicine, each focusing on different aspects. For example, U.S. biomedical scientist Leroy Hood has introduced the term "P4 medicine," which characterizes healthcare as being preventive, predictive, personalized and participatory; to date, this concept is developed primarily within the oncological field. As a catch-all term, it refers to healthcare that engages patients and users in the care process more fully than is

typical today; prefers preventive to curative goals; and tailors treatments to the individual to a greater degree than is currently the norm (Topol 2015; Sharon 2017; Swan 2012; Ekman et al. 2011; Hood 2013). Other experts refer to individualized, personalized or stratified medicine (Woopen 2011); to "disease interception" (Jessen and Bug 2019); and to precision medicine (German Medical Association 2020a).

By predicting risk factors and building individual risk profiles based on a variety of data such as diet, exercise and sleep patterns, and consumption habits, it is possible to make recommendations regarding behavior and treatments that can prevent the development of illness or reduce its severity. Digital self-tracking by means of wearables and apps – also known as "lifelogging" or, as an approach followed by a whole movement, the "quantified self" (Quantified Self 2021) – enables data on vital parameters to be collected, combined and analyzed in conjunction with behavioral and environmental data. The resulting data stream allows deviations from normal levels to be detected quite quickly, so that both users and medical personnel can be swiftly informed (→3.3, Google DeepMind's Streams app).

Users, patients and care providers can thus engage in proactive action, promptly taking any steps necessary to increase the chances of staying healthy or of detecting diseases at an early stage (Hahn and Schreiber 2018: 342). For example, ambient assisted living (AAL) environments create synergies by linking smart home applications, virtual assistance systems and telemedicine technologies, collectively contributing to prevention and early detection, and helping to increase patients and users' independence and quality of life (→3.3 Philips Ambient Experience for Healthcare Project) (Manzeschke et al. 2016; Rubeis 2020). This can improve residents' health and quality of life, and support them in making behavioral changes.

However, for such improvements to occur, patients and users must actually implement the measures recommended, and make changes to their lifestyle. As smoking-cessation, exercise and diet-change programs have long shown, this is often a difficult hurdle. Thus, the actual efficacy of these applications needs to be examined in greater detail. However, tech giants generally place a low priority on such follow-up studies. This is because their business models are already successful enough once a product such as a wearable has been sold, or an app has been downloaded and used for a short amount of time.

Self-tracking can also "promote an exaggerated pursuit of optimization that is detrimental to health, along with a medicalization of 'natural' life processes" (German Ethics Council 2017b: 120). In extreme cases, it can involve bringing the conduct of a person's entire life, or at least large parts of it, under health-oriented scrutiny. As desirable as health-promoting behavior may be, health is not the highest good toward which all behavior in life should for ethical reasons be directed. In addition, a one-sided fixation on health matters, continuous self-observation using technical devices, and the determination of one's own individual risk of developing certain diseases such as Alzheimer's, for instance through genomic analysis or the identification of biomarkers, can be associated with elevated levels of psychological and physical stress (ibid.: 198) (Woopen 2016, V1).

The mass digital collection of data with the goal of optimizing health and guiding behavior leads to a kind of "datafication" of the human being – that is, a "transfer of physical, sociological or psychological conditions into informatically coded datasets" (Wiegerling et al. 2019: 445). This transfer into the digital cannot capture everything about a human. Much in fact cannot be translated into a binary logic. Above all, this excluded category includes the subjective perspective from which a person perceives their own self and everything around them, and from which they assign meaning to the world.

The complexities of a person's perception, feelings and actions cannot be captured digitally; nor can the experience of meaning in life. The self, the I, experiences a meaningful or not meaningful life as a unit of body, mind and feeling. According to this view, dealing with the person as if he or she could be completely digitized would not do justice to the essence of their being, or to their dignity as a human. In addition, this could lead over the long term to a loss of differentiated individual personalities, due to the emergence of a data-based "one-dimensional image of man" (Selke 2016: 329). To preserve individual freedom and self-determination, this should be countered with a preventive approach that would in any case be desirable in itself.

HUMAN DIGNITY

The construction of comprehensive individual profiles based on algorithmic analysis of personal data also raises questions about the integrity of the personality, another issue relevant, amongst others, to human dignity and freedom. The construction of personal profiles, or "profiling" is defined under Article 4 (4) of the GDPR[121] as "any form of automated processing of personal data" carried out "to evaluate certain personal aspects relating to a natural person, in particular to analyse or predict aspects concerning that natural person's performance at work, economic situation, health, personal preferences, interests, reliability, behaviour, location or movements."

Ultimately, profiling "involves making deductions (drawing conclusions) on the basis of input data" that may involve actual or perceived "properties" of the individual or serve as a prediction of future behavior (Data Ethics Commission 2019: 99). This generates privacy risks, along with the possibility that personality profiles could be used to control and manipulate people (ibid.: 36).

Thus, "the individuality of the person can be considerably reduced by the normative power of data" (Heyen 2016: 6), a circumstance that would limit that person's freedom and narrow his or her opportunities for self-determination.

Technical improvements in prediction and prevention, and in the early detection of diseases, offer patients and users more options as they make decisions and act. This consequently gives them more responsibility. It expands the space for self-determination in which users can and must weigh for themselves the advantages and disadvantages of digital self-tracking technologies as used for health purposes. Assessing trade-offs in this way is an element of digital literacy, and is necessary in order to engage in digital self-determination. Digital literacy in the healthcare context is here understood to refer to the ability to select and use digital technologies in accordance with one's own values; to operate them correctly; and to find, critically evaluate and use health information online (Woopen et al. 2016: 34).

FREEDOM AND SELF-DETERMINATION

The increasing quantity of readily accessible health-related knowledge is also changing patients and users' role in the relationship between physicians and patients (Ekman et al. 2011; Skär and Söderberg 2018), as well as in the integrated healthcare context. On the one hand, this can help empower patients, and lead to a more efficient, partnership-based and self-determined treatment process. The new relationship relativizes health professionals' traditional monopoly on knowledge, which

121 See above, Footnote 24.

Examples of technologies relevant to security and privacy

ALIBABA
According to a New York Times analysis, the COVID-19 Alipay Health Code contact-tracking system provides real-time data on whether someone is an infection risk, while also sharing this information with the police, potentially creating a model for new forms of automated social control that could persist long after the end of the pandemic (Mozur et al. 2020) (➔3.2).

META (formerly *Facebook*)
The facebook social network contains functions that identify supposedly suicidal persons, to the extent allowed by locally applicable data protection regulations. For example, Meta (formerly Facebook) monitors what people write online, as well as the reactions of those who respond. If these processes identify a person suspected of being suicidal, employees decide whether to inform the police (Kaste 2018) (➔3.1 and the nuanced reflections of German Ethics Council (2017b: 246-247)).

GOOGLE
One controversial aspect of virtual assistant systems is the capability to listen continuously and analyze all voice-based information (Subcommittee on Antitrust, Commercial and Administrative Law 2020: 314). For its series of smart home products, for example, Google has already had to admit to flaws in its compliance with data security rules. Media reports have indicated that the devices had the capacity not only to listen after activation ("OK, Google."), but also to constantly analyze and process everyday sounds (Krempl 2020; Quach 2020) (➔3.2).

can in turn free patients from the constraints of physician paternalism. As patients and users participate and assume more responsibility, this contributes to a "democratization of medicine" (Topol 2015). In the P4 context, digital technologies not only facilitate data collection and processing, but also communication and networking, and thus participation.

On the other hand, there is also a risk that patients and users may find themselves overwhelmed. If basic skills such as health literacy, digital literacy and digital health literacy are overtaxed, this can produce situations in which data is not collected and classified correctly; this may in turn lead health professionals to initiate inadequate courses of treatment, endangering patients and users' health (German Ethics Council 2017b: 161).

PRIVACY

SECURITY

The digital collection and processing of personal data, especially in networked systems, raises far-reaching questions about the protection of privacy and security.

Technologies that primarily fulfill non-health functions in everyday life, such as smartphones and digital voice assistants with their various applications, demand particular attention in this regard. These devices blend diverse functions such as telephoning, playing games, communicating via social media, navigating the internet, searching for information, listening to music, measuring various aspects of the user's behavior and so on. In a networked world, this creates myriad tracking possibilities, and presents a gigantic challenge with regard to protecting privacy. Shoshana Zuboff has coined the term "surveillance capitalism" to describe this phenomenon (Zuboff 2018). To be sure, the collection of a broad range of data types from within a person's everyday behavior could help in constructing risk profiles for individual patients and users, subsequently leading to better prevention-focused recommendations – provided, at least, that these recommendations are scientifically grounded. However, such a system also risks undermining privacy protections and even the integrity of the personality.

JUSTICE AND SOLIDARITY

Health is known to be influenced quite significantly by socioeconomic determinants (WHO 2004). In some cases, the use of digital technologies and applications can positively influence these determinants for some people, or at least offset disadvantages. Strengthening prevention could be particularly beneficial for such groups, with digital technologies thus contributing to greater equity. For example, it is conceivable that low-threshold digital access to health information could compensate for relatively low educational attainment, which is an important determinant of health. However, access alone is not enough; potential users must also have the motivation and sufficient skills to take advantage of this access, and must ultimately change their behavior. There appears to be considerable need for further research and development in this area in order to design services so that they actually have this kind of impact, particularly among groups of relatively low socioeconomic status (see, for example, Satterwhite Mayberry et al. 2019).

In this regard, digital health services could be an excellent means of closing care gaps in underserved areas such as rural regions, and of reducing health inequalities more broadly – for example, by offering telemedicine services specifically to groups that previously had little or no access to medical care. However, this requires that these groups also have the technical ability to access and use the digital services. The widespread availability of smartphones today serves as a good starting point. But this in itself is not enough, given that disadvantaged socioeconomic conditions are often closely associated with low levels of digital and health literacy (Stormacq et al. 2019). If the hoped-for benefits of digital health technologies are indeed to create equity of access across the population, the aspects of digital skills and user motivation must also be taken into account (see, for example, Western et al. 2021).

The experts interviewed for this study predict that telemedicine and hybrid healthcare solutions will make significant future contributions to closing care gaps in rural areas. Moreover, they expect these technologies to help reduce global health disparities. However, some also fear an expansion of the social phenomenon known as the “digital divide” or “digital gap” (Ibrahim et al. 2021; Cornejo Müller et al. 2020; Marckmann 2020; IBC 2017). The digital divide refers to inequality in access to digital services and products. This can be associated with a variety of causes and contexts (education, socioeconomic status, age, etc.) (Cornejo Müller et al. 2020; Schüz and Urban 2020). In some cases, populations within a given country or entire national populations worldwide already experience major inequities in accessing healthcare services; if the digital divide were to additionally place digital healthcare services out of their reach, these populations would find themselves subject to multiple disadvantages and discrimination (Cornejo Müller et al. 2020). The WHO and OECD report that in certain regions of the world, socioeconomically better-off individuals have extensive access to good-quality digital infrastructure; this circumstance already leads to the systematic exclusion of certain groups, a fact which became increasingly evident during the COVID-19 pandemic, for example (WHO 2021a; OECD 2020).

The potential for discrimination due to the use of algorithmic and in particular AI-based technologies also raises questions relevant to justice. Such systems can produce systematically biased or incorrect results due to the use of incomplete or biased datasets[122] to train the AI systems, for example. Technical and methodological decisions, such as the choice of variables when setting optimization objectives, can also yield poor-quality results. This can lead to specific individuals and groups (such as women, ethnic minorities, people with rare diseases, people with disabilities, or intersex and transgender people) being unjustifiably systematically disadvantaged or excluded (Data Ethics Commission 2019: 167-168; Central Ethics Commission of the German Medical Association 2021, A7).[123]

122 See, for example, the facial recognition technologies separately produced by Amazon and Google (Wiggers 2019; Kühl 2015).

123 See, for example, Central Ethics Commission of the German Medical Association (2021); WHO (2021a); Data Ethics Commission (2019); Gianfrancesco et al. (2018); Orwat (2019); Obermeyer et al. (2019); O’Neil (2018); Weichert (2018); Cain (2015).

For example, in the United States, it has been shown that at the point of being released from the hospital, women with coronary heart disease (CHD) had on average received lower-quality care than men with the same condition, and that this was associated with a higher mortality rate after three years (Li et al. 2016). If this underlying mortality data were used to train an AI system without adequate consideration of the data relating to treatment disparities, this could influence the results and recommendations produced by the AI system in such a way that women would continue to receive worse treatment than men (Baumgartner 2021).

Sociologist Stefan Selke has coined the term "rational discrimination" in reference to the social effects of widespread self-measurement (Selke 2016). Typologically, Selke locates this social phenomenon between "social discrimination", which places people at a disadvantage on the basis of group-specific characteristics (age, gender, ethnicity, etc.), and "statistical discrimination", which occurs when incomplete information about people is supplemented by probabilistic assumptions (origin, qualifications, etc.). Rational discrimination occurs when "individual values are compared with group, average or ideal values" that have been defined in advance as standard or normal values, and which might be referred to as "the corridor of human evaluability" (Selke 2016: 323-324).

Questions of equity also arise with regard to use of technologies to determine health insurance companies' tariff and premium structures. For example, in a statutory health insurance system based on the principle of solidarity, as exists in Germany, "designing health insurance tariffs fairly (…) requires balancing the idea of equity with regard to policyholders' ability to pay with the conditions of a healthcare system financed on the basis of solidarity" (German Ethics Council 2017b: 224). The German state-managed health insurance system is fundamentally not designed to take individual risk levels into account when calculating premiums, as it is based on the principle of solidarity; this means that every insured person, as part of an extended community of risk, is equally entitled to receive help in a situation of need, regardless of why or how he or she is in that situation. Thus, for all insured persons, premium levels are equally based on the individual capacity to pay, and not on the individual risk of falling ill.

Nonetheless, it is also possible to create incentives for healthy behavior within this system, for example in the form of benefits or bonuses provided to those who adhere to certain behaviors. However, within the various kinds of insurance models based on behavioral and lifestyle data, certain groups are problematically excluded from perks. This may be because there are certain actions they are unable to take – for example, wheelchair users cannot count steps – or do not desire to take. There can be various reasons for not wanting to take such actions, including a wish to protect one's privacy. Since living conditions are often not subject to individual control, the principles of solidarity require that, when health insurance tariffs reward preventive measures by providing policyholders with financial bonuses, these benefits are available to all insured persons to the same extent, and that the policyholders can consciously decide for or against their use (German Ethics Council 2017b: 224-225).

Health insurers could even make preventive behavior obligatory, or introduce a principle of fault into the system – for example, if a failure to act preventively had a negative impact on the insurance benefits provided. However, this would lead to a loss of solidarity, and would fundamentally undermine the solidarity-based nature of the system. This said, it is not completely unimaginable that individuals could be required to contribute to the costs of treatment made necessary by their own actions. In this regard, it should however be borne in mind that due to the complexity of biological mechanisms, it is rarely possible to trace the causal origin of an individual condition back to a specific patient's behavior. Rather, such relationships can usually be only depicted in a statistical way (Schmitz-Luhn 2015: 123-130).

SUSTAIN-ABILITY

Technology-based innovations can improve the efficiency of resource use, for instance by optimizing administrative processes and the provision of care. In this regard, they can help to achieve economically and ecologically sustainable development goals (Data Ethics Commission 2019: 47). Yet such innovations themselves consume immense amounts of resources, for example due to the perpetually rising energy requirements associated with AI development and the use of blockchain technologies (van Wynsberghe 2021; WHO 2021a; Data Ethics Commission 2019). Numerous studies have testified to AI technologies' high levels of carbon dioxide emissions and related environmental impacts.[124]

UNESCO's International Bioethics Committee (IBC), in its "Report on Big Data and Health," additionally points to the mountains of e-waste generated by the ever-shorter product cycles characterizing items such as smartphones and wearables, as well as all the environmental and social sustainability issues associated with the extraction of the rare earths for use in electronic devices (IBC 2017). Preventive care can reduce costs both with regard to individual treatment and within healthcare-sector structures more broadly. However, these savings must also be compared with the costs incurred by engaging in more comprehensive prevention. The final evaluation must be based not only on which option results in greater financial savings, but also on societal values such as the value of health.

IN SUMMARY, technology provides opportunities to significantly increase the importance of prediction and prevention as compared to therapy and rehabilitation – ideally with the consequence that illnesses can be prevented or detected early, thus reducing their severity. Technologies such as digital self-tracking mechanisms and recommendation systems can promote behaviors that preserve and promote good health. This in turn expands users and patients' options for decision-making and action, gives them more individual responsibility, and increases the degree to which they participate in their own care. Changing roles in the relationship between physicians and patients, as well as in an integrated care environment more generally, can make treatment processes more efficient and give them a more partnership-based character, while also facilitating a democratization of medicine. However, patients that fixate single-mindedly on health issues, leading their lives disproportionately in accordance with the dictates of health, risk harming themselves both psychologically and physically.

AI-based systems, algorithmic profiling mechanisms, and possible tracking and monitoring capabilities all create further challenges associated with potential discrimination and manipulation. If patients and users lack skills in using the technologies, this can also produce health risks. Technology can create or expand access to health-promoting digital resources and healthcare services; however, it can also exacerbate inequities. This is also true of data-based insurance tariffs and bonus models. The intensive use of resources and the associated environmental impact, the generation of large amounts of electronics waste, and the need to mine rare earths to manufacture electronic devices also pose challenges in terms of sustainability.

124 See, for example: Strubell et al. (2019); Preetipadma (2020); Agravante (2020).

TABLE 2: **At a glance – Opportunities and challenges in strengthening data-based prediction, prevention and precision medicine**

Opportunities	Challenges
Individual and public health outcomes are improved through the prediction, prevention and early detection of disease.	Natural life processes and lifestyles may increasingly be viewed through a medical lens. Risks may be poorly understood, and individuals may lack the skills to deal with risks appropriately.
Digital self-tracking mechanisms and recommendation systems can encourage behaviors that preserve and promote good health.	Health becomes seen as the most important value in life, to the extent that all other values become subordinated to health like in a kind of health dictatorship.
As people become more informed, they expand their options for self-determined decisions and actions.	A fixation on health issues and constant self-tracking can create psychological and physical stress. A one-dimensional, reductionist view of human beings may develop (datafication). Algorithmic profiling can contribute to discrimination and manipulation.
The scope of people's individual responsibility expands.	Individuals may feel overwhelmed by responsibility, and develop feelings of guilt.
Patients can become more empowered in their relationship with physicians and in integrated healthcare settings.	The relationship between doctors and patients can be jeopardized by incorrect information and dysfunctional communication. People with poor digital-health literacy may find themselves overwhelmed, or even suffer harm.
Treatment processes become more efficient and partnership-based.	People who lack skills in dealing with health-relevant technologies (digital literacy, health literacy) may be exposed to health risks.
The expansion of patient participation and responsibility promotes a democratization of medicine.	Tracking and surveillance technologies pose privacy and security risks. Individuals and groups with poor digital skills or poor access to technologies face greater risks of discrimination.
Digital technologies can compensate for the health disadvantages associated with socioeconomic determinants.	Inequalities in access to digital products and services may be worsened (digital divide / digital gap).
Digital healthcare offerings can help close gaps in care and reduce health disparities.	Algorithmic or AI-based systems pose discrimination risks, and can be associated with barriers to access.
Health-promoting behavior can be encouraged through behavior-based insurance tariffs or health-insurance bonuses.	The direct or indirect introduction of a fault principle slowly undermines the solidarity-based nature of the statutory health insurance system.
Optimizing supply and administrative processes can lead to a more efficient use of resources as well as the realization of sustainable development goals.	The technology-driven increase in energy and resource consumption produces negative social and environmental effects. A large amount of electrical-device waste is created. The intensified mining of rare earths leads to environmental, economic and social sustainability problems.

Source: Bertelsmann Stiftung

4.3.2 MULTIDIMENSIONAL CHANGE IN COMPETENCIES OF HEALTHCARE PROFESSIONALS

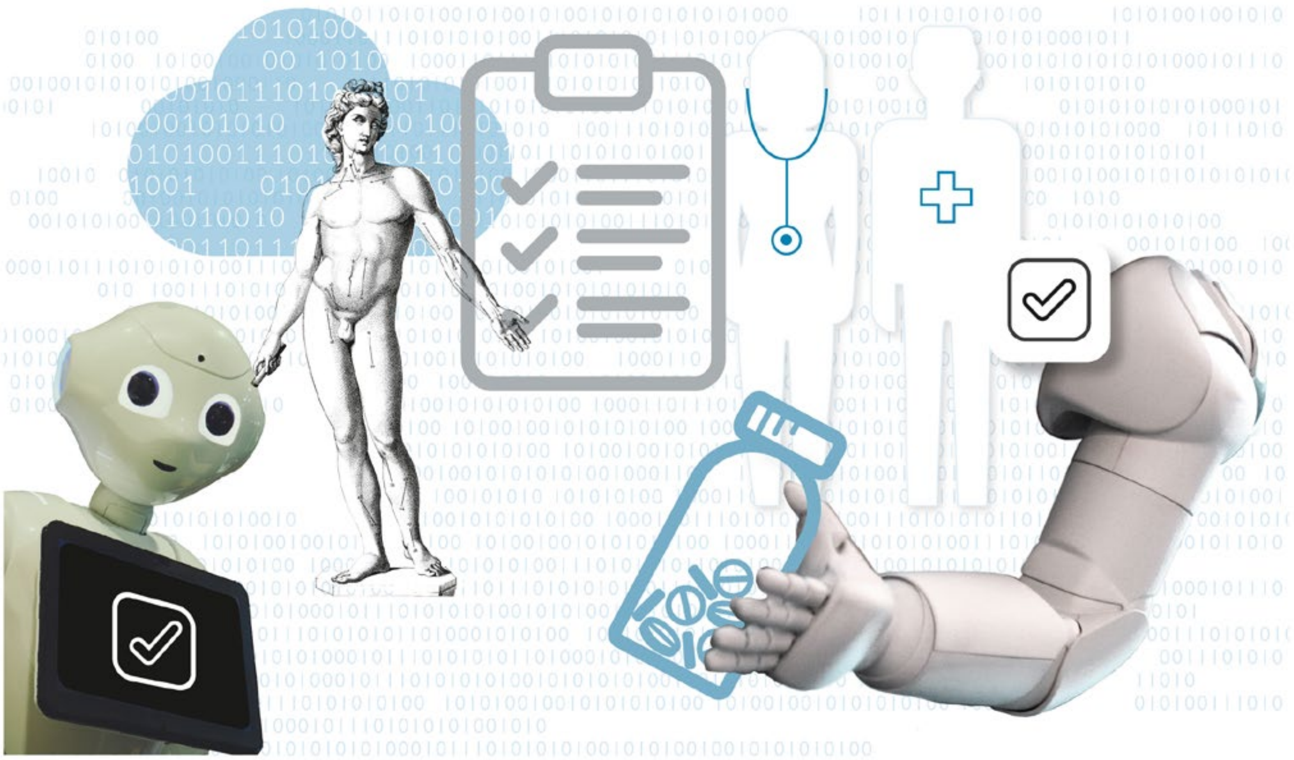
If day-to-day medical practice evolves into digitalized healthcare as envisioned by the advocates of P4 medicine, healthcare professionals will need different skills than those most commonly found today. This will include being able to deal with information technology systems and incorporate them critically into one's own actions; being willing and able to work in a patient-centered way both in networks and in healthcare teams; being willing and able to communicate with increasingly well-informed patients who have access to their own health data; and being able to take responsibility for engaging in critical reflection when using algorithmic systems, especially AI-based decision support systems. The skills demanded of healthcare personnel, and thus also the self-conception of the healthcare professions themselves, will change considerably. School curricula and training and continuing education programs will have to be realigned accordingly.

Healthcare professionals are already being confronted with continuously growing volumes of patient data, from which they have to select and evaluate the data relevant for their decisions on care (Central Ethics Commission of the German Medical Association 2021). In this regard, technologies such as clinical decision support systems (CDSS) (e. g., Siemens Healthineers AI-Rad Companion →3.3) and virtual assistance systems (e. g., IBM Medical Sieve →3.3) can play a key role in day-to-day medical practice. This is producing a shift in the profession's core set of competencies. Traditionally, health professionals have served as the sole experts when treating patients; now, this role is evolving into a mediation or advisory function between technologies and patients, and physicians take responsibility for assessing the recommendations and findings produced by data- and AI-based technologies.

At the same time, practitioners are dealing with potentially better-informed or at least more comprehensively informed patients, who are taking a much more self-determined approach to their personal healthcare, and are able to (help) shape the care they receive (Skär and Söderberg 2018). Yet patients still need a kind of intermediary in the treatment context who combines digital competencies with medical expertise in a meaningful way, and who can use these skills to construct adequate treatment plans. This shift will also require healthcare professionals to develop and cultivate new skills such as digital health literacy (SVR 2021: 272–277). This dynamic gives rise to a number of issues, primarily relating to the transformation of medical job profiles and the emergence of new jobs; however, as technologies become increasingly integrated into everyday treatment practices, additional concerns relating to safety, reliability and the allocation of responsibility will also emerge.

HEALTH

The use of technology can save time and reduce physical and psychological burdens on healthcare workers, thereby protecting their own health. For example, administrative tasks have been shown to consume approximately 17 % to 24 % of physicians' workdays. This expenditure of time correlates with lower levels of professional satisfaction (Woolhandler and Himmelstein 2014; Rao et al. 2017), is detrimental to patient care (Rao et al. 2017), and can produce unnecessary costs (Erickson et al. 2017).



The potentially saved time offered by various technologies can also lead to lower levels of physical stress for medical staffers. For example, radiologists who regularly analyze large volumes of imaging material increasingly suffer from eye fatigue that can affect the quality of their diagnostics (Waite et al. 2017). Overall, the incidence of job-related psychological distress is higher within the health professions than in the general population. This is associated with long working hours and demanding situations, among other factors, and can also be correlated with a lower quality of care (EXPH 2019: 21; Shanafelt et al. 2012; Amoafo et al. 2015; Tziner et al. 2015). Accordingly, by easing the burden on healthcare professionals, technological support has the potential to have a positive impact on the quality of care, as it could reduce the volume of human-made diagnostic or treatment errors (Stillman 2018; Rahimi et al. 2018; Sutton et al. 2020). However, this requires that the systems used for such purposes, such as CDSS tools, produce safe and reliable outcomes.

FREEDOM AND SELF-DETERMINATION

Technological support provides healthcare workers with more time, thus allowing them to practice their profession more freely and in a more self-determined manner. Ideally, they can use this extra time to focus more fully on patients, especially by engaging directly with them. This can increase the subjectively perceived quality of care, boost patient satisfaction and improve patient adherence to treatment plans (Chandra et al. 2018). In addition, costs are reduced, and improvements in physician-patient relationships and patient satisfaction correlate with improved health outcomes (Kenagy et al. 1999; Lobo Prabhu et al. 2018; Kennedy et al. 2014).

However, healthcare professionals can use the time they gain in a self-determined manner for patients' benefit only if they are not prevented from doing so by external incentives or motives that have little to do with patient well-being. The volume-based billing system currently used in most German inpatient care settings does not provide incentives for a "value-based care" approach (Porter 2010), or for the consequent increase in the quality of care. Rather, there is a danger that more and more patients will be processed using automated tools, or that the number of relatively well-paid staffers will be reduced (DKG 2019; German Ethics Council 2016).

When technologies such as bots and avatars begin playing a part in or even altogether replace the interpersonal relationship, there is a risk that the relationship between patients and healthcare professionals becomes further depersonalized (Remmers 2019). This is a problem, as human contact is considered indispensable in healthcare (European Parliament 2016). Furthermore, it has been observed that practitioners make riskier decisions in virtual consultations than when engaged in face-to-face conversations (Lee et al. 2015), which means patient safety may suffer as a result. The treatment process is not limited solely to making the correct clinical diagnosis; rather, empathy and communication are also vital (Meskó et al. 2018), requiring healthcare professionals to possess human and communication skills that go beyond the realm of purely medical expertise.

Technologically supported process optimization can simplify workflows considerably, making them safer and saving both time and money. Yet automating and standardizing workflows, as well as the use of CDSS systems, can also narrow healthcare professionals' freedom of decision and therapeutic flexibility. A considered balance between these factors is thus necessary. Such decisions should not be made solely with a view to economic advantage; rather, staff members' self-determination and patient well-being in particular must also be taken into account. That said, physicians, for example, may in some cases be happy to relinquish responsibility for a treatment decision to a technological system such as a CDSS; practitioners can experience great psychological strain due to their own errors, even if these are only subjectively perceived (Rodiewicz et al. 2020; Sirriyeh et al. 2010).

Nevertheless, treatment decisions always include decisions about values. On the one hand, the practice of evidence-based medicine is based on scientific knowledge, which can now be processed and made available more efficiently by algorithmic systems than is possible simply by individual physicians reading professional journals. On the other hand, it is grounded in medical experience derived from treating many different patients. At the same time, evidence-based treatment must always be oriented toward the well-being of the patient. This means that the patient's self-determination must always be taken into account via a partnership established between doctor and patient (German Ethics Council 2016) – something that cannot be replaced by algorithmic systems. Due to their complexity, human feelings and emotions, which are a critical aspect of this relationship between physician and patient, cannot be represented in technological models (Cabitza et al. 2017). For this reason, CDSS mechanisms, for example, can contribute important information to joint decisions, but should not be given full responsibility for making them.

"Humans are morally responsible for their actions, and there is no escaping this moral dimension. Humans are responsible for the goals they pursue, the means by which they pursue them and their reasons for doing so" (Data Ethics Commission 2019: 40).

The potential for freer and more self-determined professional practice can also be illustrated in the nursing field, using an example from the area of palliative care. The use of so-called deep learning neural networks for the purposes of technology-based decision support in such settings has improved the quality of care, while additionally enabling non-physician staff members to act more independently of physicians and be more proactive with patients (Avati et al. 2018). This points to the possibility of extending nursing staffers' occupational competencies through the use of appropriate technologies, without the need for ongoing supervision by physicians or continuous consultation in each individual case.

The future is likely to bring substantial shifts in the sector's skill requirements, changes in job profiles and even a revised understanding of professional roles. As such, there is a risk that the current generation of healthcare personnel will be overwhelmed by the rapid digital developments within care settings. If cooperation between people from different health professions is to function smoothly in integrated care environments, responsibilities must be clearly distributed. Those involved must have a basic understanding of the competency profiles of the different professions involved, including the new job profiles as necessary. In addition, there is a growing risk that technologies will cause more stress and thus generate more inefficiencies than they eliminate. This strain can be produced by the imposition of new time burdens; the use of new technologies without sufficient training; and a (subjectively) perceived loss of self-determination, responsibility and security (Virone et al. 2021; Safi et al. 2018).

People required to use new technologies can be subject to so-called technostress, described by psychologist Craig Brod as a person's inability to deal with technologies in a healthy manner (Virone et al. 2021; Brod 1984). This phenomenon is directly associated with the way such technologies are designed or integrated into the work environment; for example, less complex technologies are perceived by users as being more user-friendly (Virone et al. 2021). A lack of digital literacy is also a barrier to the use of new technologies. This is sometimes due to a lack of openness and a mistrust of new technological developments, although low-quality digital infrastructure can also play a role.

PRIVACY

This distrust can also relate in part to a desire to protect one's own privacy as an employee or other healthcare professional. Tracking and monitoring technologies intended to optimize care processes and the quality of care can turn into far-reaching elements of control that fail to protect employees' privacy and personal integrity sufficiently. However, this complex problem is not specific to the health professions, as it appears to a similar degree in other professional settings (Data Ethics Commission 2019; EGE 2019).

Potential dangers can also arise when AI-based solutions themselves function in a way that developers do not entirely understand. Especially in the case of deep learning approaches, such systems and their results are not fully transparent, externally comprehensible or explainable (see Pasquale 2015; Floridi et al. 2018; Robbins 2019; Montani and Striani 2019). This so-called black box medicine poses numerous risks with regard to the ability to adequately review decisions, and with respect to possible discriminatory effects (Žliobaitė 2017; Obermeyer et al. 2019) (→4.3.1). For example, AI systems trained with biased datasets can produce diagnostic and treatment recommendations that are inadequate and harmful to individual patients.

SECURITY

Another problem can arise when past misdiagnoses or inadequate medication prescriptions are included in the data used to train AI system (Zikos and DeLellis 2018). Inaccurate results can be "correctly misinterpreted" (Cabitza et al. 2017: 517; Caruana et al. 2015) by the algorithm; however, they will directly jeopardize patient safety in the medical treatment context if human experts fail to reflect on such errors in a professional and technologically competent manner, and do not act accordingly. These risks generating a problematic diffusion of responsibility, which in turn creates far-reaching liability and burden-of-proof issues should treatment errors and adverse events occur (Magrabi et al. 2019).

At the same time, an overreliance on technology can impair a user's professional skills (Sutton et al. 2020). The use of technology not only requires a diverse set of competencies; it also substitutes for skills and abilities that are no longer acquired or trained, potentially contributing to de-skilling (Hoff 2011; Cabitza et al. 2017). Thus, when technical systems fail, healthcare workers can no longer respond appropriately, which can become a safety issue for both staff and patients (Cabitza et al. 2017; Tsai et al. 2003; Povyakalo et al. 2013). In addition, an excessive trust in technology among healthcare workers can lead to a loss of confidence in the self (Cabitza et al. 2017).

Another safety problem can be brought about by so-called alert fatigue. When algorithmic systems set off alarms too frequently, practitioners tend to disregard them, even though they may be drawing attention to something of clinical importance (Sutton et al. 2020).

SUSTAINABILITY

In terms of sustainability, integrating technological support into everyday treatment practices can help make healthcare more economically and socially sustainable (Hütten 2019; Willyard 2019; Topol 2019a; Kohn et al. 2014; Piccininni 2018). Technologies that support diagnostic imaging offer a good example in this regard (Bizzo et al. 2019; Bhatia et al. 2020). In addition, CDSS evaluations indicate that practitioners' adherence to evidence-based medical guidelines (e.g., mammography and colonoscopy guidelines) can be improved, which correlates with better treatment outcomes (Murphy 2014). In the long run, this may also be more cost-effective, for example by leading to lower hospitalization rates (Khan et al. 2010; Contreras and Vehi 2018; McCowan et al. 2001; Murphy 2014). This in turn could help make healthcare more economically and medically sustainable. However, the environmental sustainability problems caused by energy- and resource-intensive digital systems must also be taken into account (→4.3.1).

IN SUMMARY, new technologies offer opportunities for health professionals to practice their profession in a more evidence-based, efficient, self-determined and patient-centered way, while also meeting patients' growing desire for greater participation in the treatment process. In addition, new technologies can improve care quality in a sustainable and cost-effective way through improved diagnostics, by providing treatment recommendations and by optimizing processes. At the same time, the use of clinical decision support systems (CDSS) requires a high level of digital literacy, and raises further questions regarding the distribution of roles and the associated diffusion of responsibility. There is a potential for time savings, with the time gained being used to care directly for patients, and especially for direct interpersonal interaction. However, this advantage is offset by the current lack of incentives to use the resources gained accordingly. Any development in which automation processes could lead to an increasing dehumanization of treatment processes should without question be resisted.

TABLE 3: **At a glance – Opportunities and challenges presented by the multidimensional change in competencies of healthcare professionals**

Opportunities	Challenges
Healthcare professionals can be relieved of time, physical and psychological burdens.	Introducing new technological systems can create security risks and inefficiencies. The use of complicated digital systems can overwhelm healthcare professionals. The allocation of responsibilities may be unclear, resulting in liability questions in the event of treatment errors, among other issues. Tracking and surveillance technologies may violate healthcare professionals' privacy.
Technological support can enhance digital literacy and increase personal safety.	Healthcare professionals with inadequate digital skills may become insecure or overwhelmed, leading to safety risks.
Integrated healthcare provided by teams drawn from different health professions can improve the quality of care.	The allocation of responsibility can become unclear in integrated healthcare settings, or when technical support systems are involved. Responsibilities and lines of accountability may be misjudged if some team members' skill sets are not known or misjudged.
Improved diagnostic and therapeutic capabilities can improve the quality of care.	Technologies will not be used if healthcare professionals do not recognize their benefits. Automation and the depersonalization of care can create safety risks. Systematic biases and a lack of transparency in algorithmic systems (black-box medicine) can create discrimination risks. Healthcare professionals lose skills that are replaced by the functioning of technological systems, and can no longer apply these skills when such systems fail.
Integrated healthcare environments can place a stronger focus on the patient, thus allowing for more patient-centered care.	A lack of motivation, poor communication skills and inadequate digital literacy among healthcare professionals impede the development of patient-centered care. Automated procedures can dehumanize the treatment process. Instead of producing more time for treatment and conversations with patients, technological advances may result in a reduction in the number of healthcare professionals. When delegating decisions to clinical decision support systems (CDSS), healthcare professionals may not give adequate consideration to patients' self-determination rights.
Technology-supported process optimization can make work practices more time- and cost-efficient.	Technological systems can potentially lead healthcare professionals to abdicate responsibility, while also limiting their options for treatment.
Healthcare professionals can exercise their professions in a more self-determined way as the scope of possible actions expands.	Predetermined decision-making and action options, especially when overly strict or difficult to understand, can limit health care professionals' self-determination.
New job descriptions are emerging in the healthcare sector.	The distribution of responsibilities and the skill sets needed to carry out specific health jobs are unclear.

Source: Bertelsmann Stiftung

4.3.3
MONOPOLIZATION AND DISSOLUTION OF SECTORAL BOUNDARIES DUE TO DIGITAL HEALTHCARE

The tech giants' activities are also transforming underlying healthcare structures. In a highly networked system, the digital availability of health data renders sectoral boundaries[125] technologically permeable, or even eliminates them altogether. For example, it allows multidisciplinary healthcare teams to work together on patient cases (patient-centered care), regardless of whether the individual is receiving inpatient or outpatient care, or whether the care being provided is primarily preventive, therapeutical or rehabilitative.

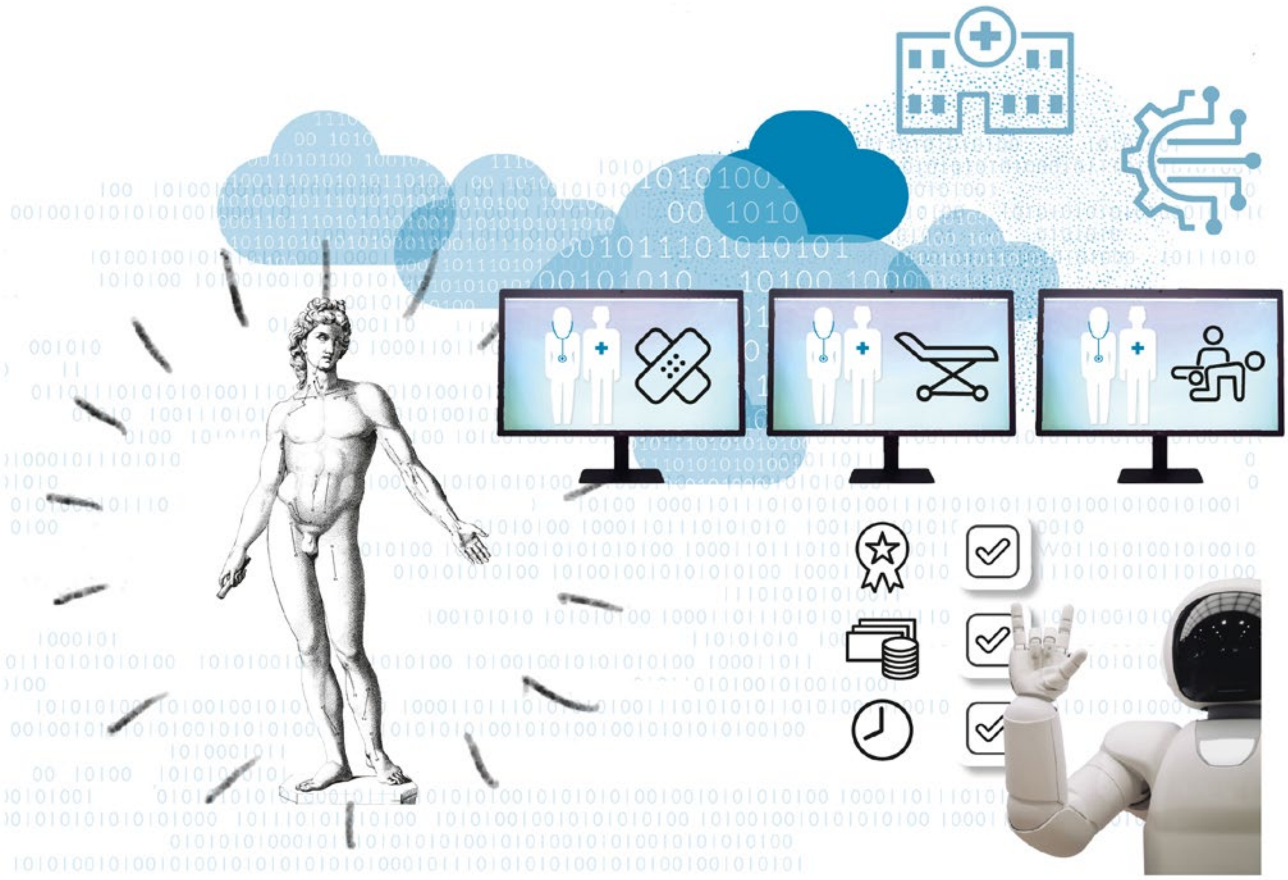
The outpatient, inpatient and rehabilitative sectors are thus becoming increasingly intertwined. Moreover, links between the public and private sectors, driven by collaborative partnerships within an otherwise competitive system, are also influencing progress in healthcare (Yildirim et al. 2016: 3; Kindermann and Lindemann 2018: 54). To develop and implement their technological innovations, tech giants need to collaborate with industry and clinical partners, for example. Conversely, these partners are also dependent upon the tech giants. This is because the large tech companies have a considerable head start in the digital healthcare field, especially in terms of their financial ability to invest in new developments, structures and highly skilled staff. They have the technological capability to collect and process huge amounts of data, and are leaders in the development of AI systems (→1.2 and →3.1). In the area of cloud computing, which is vital both for digital health research and the provision of care, the tech giants have incomparably large capacities (→3.4.1). All of this makes them strong and ultimately indispensable actors, especially in data-intensive areas. Indeed, technological progress in this digital realm seems almost inconceivable without their participation – a circumstance that gives them a monopoly-like position.

SUSTAIN-ABILITY

The German healthcare system is currently made up of "fragmented care structures" that "make it more difficult to care for patients in a coordinated and cross-sectoral way" (Klauber et al. 2019: 5). However, opportunities for data exchange within the healthcare sector promise to create value by saving time, decreasing costs and improving quality (Klauber et al. 2019: 51; Wibbeling and Raida 2019: 8-9). This in turn can contribute to social and economic sustainability. Such technologies and practices can help avoid the cost inefficiencies caused by information loss between practitioners, unnecessary (duplicate) examinations and uncoordinated treatment processes (Klauber et al. 2019: 5; Haas 2017: 31-35).

Digitally networked structures and systems, such as the networked storage of health-related data, can provide healthcare system actors with cross-sectoral access to comprehensive patient information that can be integrated into a variety of applications. This can make collaboration in the healthcare sector more effective, efficient and secure (see, for example, Siemens Healthineers

125 In some health care systems, the provision of health care services in the in- and outpatient sectors as well as rehabilitative care can have major systematic differences. For example, the German healthcare system generally distinguishes between in-patient clinical and out-patient ambulatory care as well as in- and outpatient rehabilitative care. Each of these sectors follow varying rules for the administration and reimbursement of medical care, leading to sectoral boundaries in the way healthcare can be obtained.



Teamplay Digital Platform Connect, ➔3.3). Experts regard cloud technologies as the key to realizing these gains. Such systems can also be of use in the long-term care sector. Especially in the context of inpatient care, technological solutions can help medical facilities and practitioners focus on patients' well-being, allowing them to meet competitive demands in terms of specialization, service volumes and personnel (Matusiewicz et al. 2017: 106-107).

Digital expert systems, large databases and integrated diagnostic solutions also offer an opportunity for intradisciplinary collaboration, for example by allowing "interdisciplinary diagnostic teams with massive computer support" to communicate directly with one another through a shared technology platform (Hahn and Schreiber 2018: 336). This allows medical institutions to increase their quality of care and enhance treatment efficiency, and enables physicians to invest more time in direct patient contact (Matusiewicz et al. 2017: 83). Connectivity is thus becoming a key competitive factor (Hahn and Schreiber 2018: 336).

FREEDOM AND SELF-DETERMINATION

As these sectoral boundaries increasingly dissolve, the secondary healthcare market and other health-related areas of life should also be integrated more tightly into the digital healthcare environment. This can help ensure that patients are more involved in the entire process of treatment, from the point of hospital admission to rehabilitation and follow-up care. Younger patients in particular are asking for coordinated data sharing across sectors (Böttinger and Weiß 2019: 29), which can also facilitate their self-determination.

JUSTICE AND SOLIDARITY

A thoroughly digitally networked and centralized system poses the risk of excluding people who have no or only limited access to digital health services – perhaps because they lack the requisite technical means (such as a smartphone) or have minimal digital skills, and are therefore unable to take advantage of health services made possible by digital applications (e. g., in the area of telemedicine). Such a system would not meet ethical requirements relating to equity of access or participatory justice. Under such circumstances, these individuals would likely receive a poorer quality of care and be in poorer health than participating, networked patients, thus producing a problematic two-tier digital medical system (dpa 2018; Misslbeck 2019; Hardt 2021: 471).

Similarly, certain groups of people could be excluded if, for example, tech giants were to offer high-quality integrated care exclusively to their employees and their dependents. Examples of this today include Apple with its so-called AC Wellness Clinics, and Amazon with its Amazon Care telemedicine service (→3.4.5). The large corporations could, theoretically, open their own healthcare facilities accessible solely to very wealthy patients. However, a statutory healthcare system based on the principle of solidarity must keep a close eye on the market share held by private insurance and care, while always ensuring that financially less able citizens have access to the solidarity-based system. There is also a risk that the statutory and private healthcare sectors may compete for scarce resources such as skilled nursing personnel.

A digital divide is additionally becoming apparent at the system level. If established healthcare-system structures and their actors are unable or unwilling to adopt the technologies and processes developed by and with tech giants, perhaps due to inadequate regulation or a lack of technical skill, they may fall behind their peers elsewhere in the world. This in turn could ultimately undermine the quality of care. In fact, experts have argued that the German and European regulatory environments could dissuade technology companies from rolling out their advanced products and services there. Particularly in the German and European contexts, market and regulatory conditions are inhibiting the transformation to digitalized healthcare, because "separate remuneration budgets for the outpatient and inpatient sectors, a lack of financing incentives for the acquisition of digital solutions, and an often uncertain return on investment (…) make investment in the digital future unattractive" (Matusiewicz et al. 2017: 48).

This raises the question of whether and how technologies, applications and structures developed by the tech giants can be incorporated within or complement the state-managed care system. In addition, it is worth asking whether in Germany, for example, there is a risk of displacing the ethically well-founded, state-managed solidarity-based system, thus exacerbating the healthcare sector's potential dependencies and purely economic incentive structures. Conversely, policymakers and other analysts must consider whether inadequate regulation and a lack of technical skills in the sector may hinder or even preclude opportunities to digitalize healthcare with the tech giants' help. Hahn and Schreiber (2018) argue that disruption and cooperation need not be contradictory (Hahn and Schreiber 2018: 340). Moreover, highly efficient digital processes in particular can enhance the incentives created within a "value-based care" approach (Porter 2010), which can, in turn, increase the level of care and improve public health. Nevertheless: "Whoever has access to data will dominate the market. This is true in the field of digital health as well" (Krüger-Brand 2020: 375).

The tech giants' data-based activities in the healthcare sector have enabled them to dominate certain areas of the market.[126] This has resulted in a "fierce battle to accumulate data" between the sector's large actors (Baas 2019: 10), who are training algorithm-based systems and developing applications on this basis. The presence of a competition-driven network industry within the healthcare market poses the risk that "oligopolies led by only a few dominant players" will develop (Hahn and Schreiber 2018: 340), which in turn may produce data- and technology-driven dependencies.

DEMOCRACY

These dependencies have ethically significant implications for science and research in particular (➔3.5 and ➔4.3.4). Tensions and asymmetries may emerge, because "technology can undermine democratic structures, and its development takes place outside of democratic controls" (Woopen and Mertz 2014). Questions of justice also arise in this context. Companies possessing monopoly-like power could influence access to and the distribution of healthcare, for example with regard to specific services. Scenarios involving a more subtle exercise of power are also conceivable. For instance, by exploiting data monopolies in a nontransparent way, companies could effectively exclude certain users, thus violating the tenets of participatory justice (German Ethics Council 2017b: 224).

Given their immense financial resources, tech giants may be able to further strengthen their monopoly-like positions by absorbing potential market rivals through acquisitions, especially by buying AI and telemedicine startups (➔3.4.9). Because the giants are already large, and have very significant market penetration, they can offer startups significant scaling effects.

Amazon's activities in the pharmaceutical sector illustrate the impact of monopoly-like structures that extend across different, previously separate market segments. The company has 118 million Amazon Prime customers in the United States alone, representing about one-third of the country's total population. Providing access to medicines for this massive customer base offers it significant opportunities within the pharmaceutical sector. The company analyzes its customers' individual search queries to provide them with related drug advertisements and personalized medication suggestions. Its online ordering system, along with delivery mechanisms requiring little direct contact, give Amazon a key competitive advantage over other large pharmacy chains (Egert 2020).

PRIVACY

SECURITY

The presence of centralized, cross-sectoral platforms that collect large amounts of data also raises security issues. A so-called hospital 4.0,[127] in which all systems are networked, could become an attractive target for cyberattacks. "The sabotage of vital healthcare infrastructures and the theft of personal patient data serve as business models for extortion 4.0" (Matusiewicz et al. 2017: 52), and can result in serious privacy and security consequences. However, European cooperation could help facilitate secure data access, and so-called data trust centers could provide better data protection than is possible for small individual actors. The European Health Data Space initiative, for example, is moving in this direction (European Commission 2021).

126 In October 2020, the U.S. House of Representatives Subcommittee on Antitrust, Trade and Administrative Law released a report on the issue of competition in digital markets. It concluded that the companies analyzed (Amazon, Apple, Facebook (now Meta) and Google) held significant and durable market power in individual areas, in some cases reaching the level of monopoly power (Subcommittee on Antitrust, Commercial and Administrative Law 2020).

127 "In the near future, all hospital functions will be networked, from the hospital information system (HIS) and the connected medical devices all the way to the building services and administrative functions, producing what might be called a hospital 4.0" (Matusiewicz et al. 2017: 51).

The tech giants thus have unmatched financial power, and benefit from technologically driven scaling effects. Their products and services are helping to dissolve boundaries between the health-care system and everyday life. These capabilities bring with them the ability to shape and influence people's lives even well beyond the healthcare market.

Charting the bounds of this impact requires asking questions that extend beyond healthcare itself:

» What is the focus of research efforts?
» What products are being developed for which users and patients?
» Which applications for preventing diseases or optimizing integrated care processes are seen as particularly interesting?
» What terms and conditions are required by the various products and applications currently on the market?
» Do low-income countries and individuals also have access to digital healthcare and health-enhancing products and applications?
» Which lifestyles are defined as being particularly healthy and supported by digital media, and how are they rewarded?

If tech giants approach these issues using purely economic criteria, they will wind up pushing social and cultural lifestyles and perceptions, and thus individual lives and society as a whole, farther toward a market-oriented logic – even though some desirable progress with regard to individual and public health can also be expected. Indeed, they are already wielding such influence today via products and services that do not have a primarily health-related application, such as smartphones and social-media platforms. Should the market develop further in this direction, it is unclear whether or to what extent individuals would be able to develop and realize self-determined conceptions of a "good life" differing substantially from those professed and promoted more or less subtly by the tech giants.

What institutions and processes can ensure that technologies are used in the service of the people and the common good? What mechanisms can preserve people and societies from being forced to conform with the tech giants' visions for the future?[128] It has long been apparent that regulating the tech giants and their activities in a way that leverages their potential while also minimizing undesirable effects is a highly complex proposition. This balance is certainly of great significance within the German healthcare system. Yet within Germany, healthcare-system digitalization has proceeded at a slow pace (Thiel et al. 2018). The sector is already highly regulated, and the profit outlook for the tech giants is often relatively dim. Given these factors, policymakers and others should pay greater attention to digital healthcare's unrealized potential.

128 On this complex issue, see also Zuboff (2018). The video available via Savov (2018) is also interesting in this regard.

IN SUMMARY, the increasingly interlocking nature of the healthcare field, with barriers between sectors dissolving due to the tech giants' health technologies, is creating the potential for cost-efficient, sustainable and patient-centered care that can benefit everyone in the healthcare field. However, there are also major challenges regarding participatory justice and equity of access, security, and the tech giants' monopoly-like market positions. With their enormous data, technological and financial power, these companies can shape the healthcare sector right down to its fundamental structures. They can build parallel systems, and can shape and influence individual lives, and even society itself. In so doing, they subtly weaken individual self-determination, and flatten social and cultural diversity. However, the German healthcare system, with its very comprehensive and far-reaching regulation, is resistant to domination by the tech giants.

TABLE 4: **At a glance – Opportunities and challenges presented by monopolization and the dissolution of sectoral boundaries due to digital healthcare**

Opportunities	Challenges
Efficient cross-sectoral collaboration between multidisciplinary healthcare teams promotes more patient-centered care, and thus also health, safety and sustainability.	In Germany and Europe, overregulation and a failure to implement integrated digital structures have impeded attempts to realize the potential of digital healthcare technologies. Professional associations' political activities and a lack of data interoperability have also slowed development.
Efficient networking helps improve data access and data exchange.	Poorly designed systems and cyberattacks create privacy and security risks. Badly designed rules and structures can inhibit data access and data exchange.
Integrated, patient-centered care can strengthen patient self-determination.	The equality of access and participatory justice can be limited by a lack of technical resources and insufficient digital skills.
There is great potential to add value with regard to time and financial resources, as well as in the quality of care.	Private or even exclusive healthcare offerings and unequal access to digital resources can undermine justice and solidarity. If tech giants and their datasets are insufficiently involved in the further development of digital healthcare functions, this could hamper potential value creation and inhibit innovation.
Networking, collaboration and the promotion of "value-based care" approaches can contribute to sustainable development while dealing effectively with diversity.	Tech giants can inhibit justice and solidarity by influencing the operation of state structures or even by establishing parallel structures. If tech giants gain substantial power to shape individual and social life through the development of monopolies and dependencies (data-driven, technological and financial power), this can lead to a loss of freedom and diversity.

Source: Bertelsmann Stiftung

4.3.4
LINKING EVERYDAY CARE AND RESEARCH TO A LEARNING HEALTHCARE SYSTEM

In the following, we define research as “a process based on the core activities and principles inherent in the scientific method (methodology, systematics, need for evidence, verifiability, openness to criticism, willingness to revise), used to discover, interpret and transmit knowledge” (Weichert 2018: 97).

One idea prevalent in the research community today is the so-called End of Theory thesis, which contends that “information technologies will significantly change and even improve the process of scientific knowledge discovery” (Wiegerling et al. 2019: 402). Proponents of this thesis assume that “the increasing quantity and quality of data processing in the sciences will increasingly allow non-empirical elements (‘theory’) to be dispensed with” (ibid.: 401; Antes 2016). By expanding the volumes of data to be analyzed and using highly sophisticated data processing techniques, it should be possible to gain insights that “lie beyond the reach of previous scientific methods” (Wiegerling et al. 2019: 402). This relates not only to individual disciplines, but to the concept of scientific knowledge and scientificity in general (ibid.: 403).

In the health sector, this involves generating, synthesizing and processing diverse types of health-related data from a variety of sources. These include 1) research data from clinical trials, 2) treatment data from regular inpatient and outpatient care, 3) diagnosis- and therapy-related billing data from health insurance funds and other insurers, 4) data generated in everyday life, outside of specific healthcare or research settings, including by patients and users themselves, and 5) “synthetic data” generated artificially on the basis of real datasets, for instance to train algorithmic systems.[129]

Methodologically, the use of AI to analyze large datasets entails a fundamental problem, in that techniques of this kind identify patterns and correlations, but do not prove causalities. However, evidence of causal relationships is crucial for medical research and the evidence-based medical interventions derived from it. Against this background, it is possible to draw fundamental scientific-theoretical and methodological conclusions with respect to rendering the correlations discovered via big data-based analyses useful for evidence-based medicine (EBM). Nonetheless, scientists have warned against accepting the promises associated with big-data-based knowledge acquisition too uncritically (Antes 2016; Liang and Kelemen 2016).

There is the hope that research drawing heavily on data captured within patients and users’ everyday lives and care processes, for example using various forms of sensors, can help make complex phenomena more predictable, increase the reliability of prognoses and accelerate the discovery of new phenomena (Wiegerling et al. 2019). In this regard, the tech giants have considerable advantages relative to public sector entities, as they have access to much larger volumes of data and more powerful analytical capabilities (German Ethics Council 2017b: 116; see Wilbanks and Topol 2016).

129 See, for example: Nikolenko (2019); Drechsler und Jentzsch (2018); Wolfangel (2021).

JUSTICE AND SOLIDARITY

The conditions under which companies and other entities grant access to their data pools are important, both for the public in general and for the research community in particular.[130] Nationally and especially internationally, numerous obstacles make it difficult to access and exchange data for research purposes. Private companies, hospitals and research groups tend to consider and treat the data they collect as their own property, and regularly reject external requests to use it (German Ethics Council 2017b: 222–223; Weichert 2018: 99). More and more inaccessible data silos are emerging, a fact that may lead to a commercialization of research activities and of the scientific generation of medical knowledge more broadly.

The withdrawal of data from the public sphere also indirectly creates a problem from the ethical perspective, since it undermines the equality of opportunity and weakens participatory justice (German Ethics Council 2017b: 223). If companies and other entities unjustifiably obstruct access to collections of data, this will force researchers and others to expend new effort and incur additional costs, all avoidable, to collect the relevant data on their own. This can limit the exploitable potential of data, and may push private companies to gather data solely for the purposes of making a profit (German Ethics Council 2017b: 223), in turn also undermining important sustainable development goals.

Tech giants often use proprietary technologies – with the participation of patients and users – to collect, aggregate and analyze data in an automated way (patient-generated health data). The resulting datasets open up new potential for the scientific and research sector, by creating a

130 For more on this topic, see Mittelstadt and Floridi (2015) and Data Ethics Commission (2019).

"significant quantitative and qualitative expansion of the data base with a new density of detail" (German Ethics Council 2017b: 120). An expanded and diversified store of research data and knowledge can lead to more precise stratifications in the preventive, diagnostic and therapeutic medical fields. In addition, this could accelerate the acquisition of information and knowledge (ibid.: 121).

However, most individuals and groups do not have unlimited access to data-generating and data-processing technologies (➔4.3.1 and ➔4.3.3). This can produce conditions in which researchers have only incomplete or fragmentary data at their disposal, leading in turn to flawed scientific findings and potentially even flawed treatment recommendations derived from this data. In some cases, this imperfect data excludes or underrepresents certain classes or categories of people; the findings or recommendations based on such data can consequently contribute to discrimination, or even damage patients' health.

Furthermore, with regard to ensuring that data is both valid and reliable, there is a methodological problem in that the unstructured data collected from patients and users cannot be adequately validated (German Ethics Council 2017b: 161). This lack of quality control can produce broad variations in the quality of the data and resulting outcomes (German Ethics Council 2017b: 121; Liang and Kelemen 2016).

In addition, this "nontransparent and encapsulated data analysis" (German Ethics Council 2017b: 116) generates challenges with regard to transparency and reproducibility, and hampers the ability to reflect critically on the process of acquiring scientific knowledge. Some observers fear that this could inhibit "medical progress" and that the tech giants' vast market power could frustrate "methodological plurality in the study and interpretation of health data" (ibid.), especially since the formation of data monopolies could prevent other actors' market access (ibid.: 115). Over time, the scientific community may become increasingly dependent on the entities that hold these data monopolies (➔4.3.3).

These creeping monopolistic structures (➔4.3.3) are linked to another set of problems relevant to justice. On the one hand, researchers could be prevented from defining and pursuing their own research goals (German Ethics Council 2017b: 223; Becker 2019). Potential conflicts of interest, lobbying, and infrastructural or financial dependencies could endanger the freedom of research and constrain researchers' activities. Such factors could influence research goals – for example, as companies channel support toward findings with a high potential for profit – and entice researchers out of the field of public research into private and primarily profit-oriented knowledge generation. On the other hand, public-private partnerships (PPPs) between research institutions and tech giants can contribute to the investigation of complex research questions by pooling knowledge, expertise and resources, thus facilitating activities that would be impossible for a single institution to perform alone (Yildirim et al. 2016: 3; Kindermann and Lindemann 2018: 54). Examples of this include Intel and Google's collaborations with the National Institute of Health (NIH), Apple's work with the Harvard T. H. Chan School of Public Health and the NIH, and Meta's (formerly Facebook) projects with New York University (NYU) Langone Health medical center (➔3.5).

However, as healthcare institutions and companies share and exchange data in the context of research and development PPPs, this can raise issues related to informational self-determination, security and privacy. Sharing data, as well as storing and processing data centrally, can produce risks even if that data is initially anonymized or pseudonymized. For example, it is technically possible to de-anonymize or de-pseudonymize data of this kind, especially when different datasets are merged. Moreover, some datasets, such as certain genetic data, are difficult to anonymize by their very nature (Packhäuser et al. 2021; Lanzerath et al. 2019; Stoeklé et al. 2019).

Some technological solutions already exist today that combine increased data-handling security with the ability to conduct data-based research activities. For example, so-called swarm learning or swarm intelligence constitutes a significant technological innovation enabling decentralized datasets to be evaluated according to predefined rules (Warnat-Herresthal et al. 2021; Rüdiger 2020). Swarm learning allows data to be analyzed where it is stored – at the "edge" node, as the edge computing field terms it – rather than at a centralized location. Under such a system, the data is fed locally into learning algorithms, most often neural networks, with only the results of the data processing being passed back to the overall system or network via blockchain (Rüdiger 2020). This allows global health-related data to be integrated into a network without the data itself being shared, and without the need to store it in a central location (Warnat-Herresthal et al. 2021).

HEALTH

Ultimately, the everyday provision of care could evolve in tandem with research activities into a learning healthcare system guided by a multilevel governance model. Today, more than €1 billion is spent on healthcare in Germany every day (approximately 65% of which comes from social insurance contributions) (Federal Statistical Office of Germany June 2, 2021). Under a learning system, data associated with these healthcare functions could be evaluated by the research community, with the survey mechanisms meeting researchers' high requirements for data collection and data quality. The findings could then in turn be fed rapidly back into the care domain, supported by information technology tools such as clinical decision support systems (CDSS), for the benefit of all patients. This would allow a considerable amount of existing data from the clinical environment to be used to generate knowledge and evidence. To date, such advances have instead been made almost exclusively by implementing separate costly long-term studies, a mechanism that itself is becoming increasingly impractical due to increasing stratification. The research findings could be integrated more quickly into practice settings, and the subsequent results could in turn be evaluated scientifically, thus creating an ongoing cycle of learning.

JUSTICE AND SOLIDARITY

This could even enable more people to participate in the progress, enhancing participatory justice, because a learning healthcare system of this kind would prove especially beneficial to patient groups that are otherwise difficult to include in randomized clinical trials. For example, very old people taking many medications simultaneously could be better protected against side effects, because patterns of adverse interactions could be identified more quickly in large datasets. Similarly, a system of this kind could avoid problems of poor external validity – that is, when clinical trials' findings prove for various reasons not to be confirmed in everyday care.

Finally, the trend toward precision medicine – in which therapies are tailored to each specific patient on the basis of his or her individual data, rather than being essentially identical for everyone with the same overarching diagnosis – requires a closer connection between daily healthcare practice and the research community.

TABLE 5: **At a glance – Opportunities and challenges presented by linking everyday care and research to a learning healthcare system**

Opportunities	Challenges
Systematic scientific analysis of healthcare data leads to new insights.	AI-assisted analysis of large datasets identifies correlations and patterns, but not causal relationships. Various stakeholders may not respect the "FAIR" principles for research data sufficiently. A lack of transparency and insufficient access to data make it difficult to fully understand the results produced by algorithmic systems, and prevent critical reflection on them. When healthcare data is shared or stored centrally for research purposes, this produces security and privacy risks.
Complex phenomena become increasingly predictable, predictions become more reliable and new phenomena can be discovered more quickly, even for patients who are difficult to integrate into clinical trials.	Systematic biases exhibited by technological systems trained on the basis of inadequate data can undermine justice. Data monopolies and data silos that interfere with data access and data sharing impede innovation and diversity.
Access to a broader base of data contributes to more precise stratifications in preventive, diagnostic and therapeutic activities.	Publicly funded research can be weakened by inadequate data access (data silos) and out-of-date technology systems as it competes with tech giants, and is increasingly losing its influence in defining important research questions.
Pooling knowledge and resources via public-private partnerships (PPPs) enables the study of complex research questions.	Limited access to data-generating and data-processing technologies gives rise to discrimination and exclusion risks (digital divide).
New technological solutions (such as swarm learning) increase the security and privacy of data processing.	Heterogeneous data quality and a lack of interoperability between data from different sources inhibit innovation.
A learning healthcare system with a multi-level governance model (cycle of learning) can promote individual and public health and strengthen healthcare delivery.	The tech giants' market power threatens the freedom of research and the freedom of researchers themselves, because financial and infrastructural dependencies can influence the choice of research goals, for example. Professional associations' political activities and lobbying are hampering the digitalization of the healthcare sector. Insufficient political will, a lack of digital infrastructure and insufficient digital skills can prevent or slow the development of a learning healthcare system.

Source: Bertelsmann Stiftung

IN SUMMARY, tech giants can help forge links between everyday healthcare and healthcare research, with the goal of creating a perpetually learning healthcare system. However, a variety of challenges must be overcome in order to take advantage of the resulting opportunities. Some of these challenges arise from the tech giants' monopoly-like positions with regard to their control of data and access to algorithmic systems. Others relate to methodological problems, for example in connection with AI-supported research. In addition, it will be necessary to meet ethical requirements, such as those relating to freedom of research, equity of access and distributive justice, privacy protections, and the need to prevent discrimination against the people whose data are used.

5 CONCLUSIONS AND RECOMMENDED ACTIONS

To date, (health) policy response to growing tech-giant activity in solidarity-based, statutory healthcare systems in Europe has, especially in Germany, been rather limited, despite the fact that these companies have the potential to fundamentally transform the healthcare and medical research sectors. Given the strength of regulation in the European and the German contexts and the low level of profitability yielded by the tech giants' offerings in the statutory, publicly funded healthcare systems as the German one, it's unlikely that the German systems will quickly be "taken over" by the tech giants or that a parallel system will emerge anytime soon in the country. However, these firms' products and applications, as well as their collaborative activities with other companies, research institutes and actors, can play an important role in making healthcare more effective and efficient while, at the same time, driving a shift to patient-centered healthcare within a system structured primarily by sectors.

The tech giants have the capacity to complement and transform state structures for providing care in ways that conform to ethical standards and thus significantly advance any lagging adoption of digital technologies in healthcare, as is the case in Germany. This will require, however, establishing sound regulatory frameworks. Given the tech giants' focus on profitability and scalability, involving them more thoroughly could facilitate economically driven incentives in the care sector that work against the goals of patient well-being, fair working conditions for healthcare professionals and the principle of solidarity. These issues should be accounted for in policymaking.

Though the influence exercised by the tech giants on digital healthcare is obvious and powerful, it is also in some ways subtle. Their influence is obvious and powerful when – for example, in the case of U.S. and Asian companies – the wide use of smartphones featuring health apps and the companies' ability to directly collect and process user data makes it difficult to avoid using their products and services. The tech giants are also leading the way in developing technologies for use in specific clinical areas such as radiology. European companies in particular are concentrating on these clinically defined areas. Asian tech giants are also characterized by the fact that they are even more blatant than their U.S. or European counterparts about combining data derived from various areas of life, including those related to personal health. They also use this data to monitor, evaluate and control citizen behavior as a means of enforcing their own or, in the case of China, government-mandated requirements.

The more subtle influence of tech giants manifests in the ways they are impacting various clinical areas through strategic partnerships that include investing in other companies and acquiring start-ups. By engaging in these activities, they are consolidating their capacity to shape and define the goals of the healthcare system and research, as well as what is desirable in healthcare.

In this context, areas of single potential can, over time, generate cumulatively positive effects. By the same token, currently latent risks could in the long run combine to produce systemic risks. Moving forward, it is important to continually monitor and review the dynamics of these countervailing tendencies.

The example of health insurance companies leveraging technologies to determine their tariff and premium structures underscores a slowly sprawling development that potentially belies the principle of solidarity upon which the German system is built, most notably by instituting health insurance models and premiums based on behavior and lifestyle (➔4.3.1). For example, by incorporating technologies and applications that allow people to digitally track their own activities, incentives are created to reward healthy behavior through bonuses. The German Federal government's coalition agreement for 2021–2025 signed by the Social Democratic Party (SPD), Alliance 90 / The Greens (Bündnis 90 / Die Grünen) and Free Democratic Party (FDP) in December 2021, aims to strengthen the conditions needed for such measures, stating "They [public health insurers] increasingly have the option of granting insurees monetary bonuses for participating in prevention programs."[131]

Although these incentive systems generally reward behavior that maintains and promotes good health, certain groups are de facto excluded from any such perks (➔4.3.1). If access to benefits were to be systematically blocked, or if certain types of behavior were to be deemed obligatory and the failure to comply were to have a negative impact on the insurance benefits provided (sanctions), this could undermine solidarity and fuel the public's willingness to challenge the principles upon which the German system is built.[132] This kind of development would presumably take place incrementally over the long term and be subtle enough in many respects to remain unnoticed by many, at least in the beginning. Nevertheless, these potential effects should be thematized in current debates on the importance of preventive health behavior (➔Recommended action #1).

The example of increasingly stratified preventive and precision medicine through algorithmic profiling illustrates the fact that the activities of tech giants can also have contradictory short- and medium-term effects (➔4.3.1). Using data and technology to generate personalized risk-factor

131 Coalition agreement p. 88, line 2910 f.

132 Notable in this regard is the recently uttered demand in Germany to raise statutory health insurance premiums for those not vaccinated against COVID-19 (Spiegel 2021).

profiles that can assist in predicting the risk of disease and disease progression will undoubtedly be seen as a positive effect. However, any use of risk profiles to discriminate against, manipulate or somehow violate the integrity of an individual, possibly even in areas beyond healthcare, is likely to be viewed as a negative consequence that should be avoided (➔Recommended action #7).

Developments in the healthcare sector that have the potential to dissolve sectoral boundaries while also facilitating the creation of monopolies or oligopolies among a few tech giants illustrate the ambivalence of the long-term effects involved (➔4.3.3). Digitally networked structures and systems, as well as cross-sectoral collaboration in healthcare, can help advance a more consistent assessment and design of patient-centered care. In addition, these developments can deliver benefits in terms of time and cost efficiencies as well as an improved quality of care – thus a positive development. At the same time, they are also associated with the creation of market dominance, which can involve dependencies. Companies able to exercise monopolistic or oligopolistic power could have an outsized say in issues relevant to the access and distribution of healthcare services, and they would have the capacity to prevent other actors from innovating. This ambivalence should be addressed by a clear political commitment to patient well-being as the paramount ethical guide in advancing the digital transformation of the healthcare system (➔Recommended action #3).

Infrastructural and financial dependencies are also likely to have an impact on R&D and research communities (➔4.3.4). The emergence of entities that hold data monopolies, are able to prevent others from accessing their data and can potentially interfere with research goals could eventually jeopardize independent research and the independence of individual researchers. This, in turn, can affect who has the power to interpret and leverage specific scientific findings. Given their enormous financial resources, tech giants can further consolidate their quasi-monopolistic position by absorbing potential competition within the market through acquisitions. They are gradually able to monopolize data, technology and financial capacities in the area, and thus could potentially consolidate their power to determine the course of future developments. This runs counter to a social economic regime that is grounded in the principles of a liberal democracy. The aforementioned potential opportunities and risks should therefore be taken into account when designing government support measures targeting innovation (➔Recommended action #4).

Informed by the ethical analysis featured in this publication, the following recommended actions address social and political considerations relevant to the transformation of healthcare and the healthcare system more broadly. They are thus implicitly relevant for tech giant activities as well.

RECOMMENDED ACTIONS

1. Conduct public debates on the value of predictive health screening and preventive health behaviors
2. Promote digital (health) competencies
3. Take a clear policy position on the role of tech giants in healthcare
4. Use government support to facilitate innovation beyond tech monopolies and oligopolies
5. Advance risk-adapted regulation of artificial intelligence in the EU
6. Incorporate an ethics-by-design approach into the design, development and use of AI systems
7. Legally prohibit the use of health-related risk profiles to discriminate in non-healthcare settings
8. Develop a strategy for a learning healthcare system

1 Conduct public debates on the value of predictive health screening and preventive health behaviors

Recent data- and technology-based developments driven primarily by tech giants that are facilitating predictive, prevention and precision medicine are having a profound impact on social cohesion and how we perceive ourselves and others (German Ethics Council 2017b). Public debates as well as those conducted among policymakers themselves should address the following: What is the role of health in relation to other areas of life and society? What changes are needed to a healthcare system that engages with both the primary and secondary health markets? What role should the tech giants, which have a monopolistic or oligopolistic position in these markets, play in this context?

An awareness of systemic impacts is also relevant – at both the societal and political levels. Thus, despite all the medical benefits generated by modern P4 medicine, these developments may, in the long-term, undermine the principle of solidarity if previously non-systemic elements – such as personal culpability in the development or aggravation of an illness through certain types of behavior or the failure to take preventive action – become relevant features of the healthcare system. In addition, any measures related to predictive, preventive and precision medicine should be subject to evidence-based monitoring and evaluation. Accountable actors in the healthcare system should develop measures that are designed to counteract the individual and systemic risks identified in chapter →4.

2 Promote digital (health) competencies

Digital skills, which include digital health literacy, are essential to informed public debate and the adept use of digital healthcare products and applications. It is important that people learn early on how to properly operate and handle health-related technologies. Given the rapid pace of technological development, these competencies will have to be purported early and continuously throughout the course of their lives. Digital skills should therefore be developed and strengthened from kindergarten through retirement. The German Ethics Council advises that these skills should already be taught at school "as an interdisciplinary task in all subjects" (German Ethics Council 2017b: 271–272). This includes developing skills in managing risks, especially since predictive statements about health are usually only an indication of potential risk.

3 Take a clear policy position on the role of tech giants in healthcare

Those who use the technologies applied in the healthcare system play a special role in its transformation, and they also bear a specific responsibility in this regard (see SVR 2021). This includes patients and users as well as healthcare professionals (WHO 2021a; Topol 2019b), decision-makers in the variety of healthcare institutions representing service providers and Germany's self-governing corporatist bodies, and researchers and research institutions (➔4).

Adapted job profiles should be promoted, as should additional job profiles. Responsibilities associated with specific jobs in integrated care also need to be redefined. This should entail ensuring the reflective use of technologies as well as an ethically informed critical awareness and evaluation of these technologies – one that considers the roles played by those shaping the technologies and their framework conditions. Ensuring easy-to-understand messaging that reaches specific target groups is also relevant in this regard. A key factor here involves integrating the growing number of opportunities associated with technology into curricula for the health and medical professions.[133] Given the risk of a blind faith in technology, measures that provide guidance in the event of technological failure should be defined and taken (WHO 2021a). Being able to take a clear policy stance on the role of tech giants in healthcare is conducive to creating such structures and policies.

133 For example, if algorithm-based systems are used in the context of a specific treatment, it should be clear to the health professionals involved that technology can be of assistance to – but cannot replace – people. The European Ethics Council emphasizes in this context the primacy of human action and oversight, as well as accountability (European Group on Ethics in Science and New Technologies 2019).

4 Use government support to facilitate innovation beyond tech monopolies and oligopolies

Public investment in the data economy and the development of algorithmic systems, including AI, should primarily foster innovations that conceive of data as a common good rather than a commodity (IBC 2017). In keeping with the principles of a social market economy and solidarity-based healthcare, governments should act accordingly to prevent monopolistic structures from developing among suppliers in the healthcare market (Weichert 2018; Hoffmann et al. 2015). Whereas public-private sector partnerships can help counteract monopolistic tendencies among companies working across the data chain (Ballantyne and Stewart 2019), regulatory frameworks and funding programs are needed to influence how data is accessed and leveraged so that smaller actors can deliver innovations, particularly those targeting the common good (High-Tech Forum 2021).

In order to counter the unequal distribution of data that emerges from the monopoly-like control exercised over this data (→4.3.3 and →4.3.4), we need instruments able to guarantee authorized individuals and/or groups access to this data (German Ethics Council 2017b). This issue should also be integrated into the design of the European Health Data Space. This may involve establishing regulated data trusts (Data Ethics Commission 2019). Technological solutions such as synthetic data (→Recommended action #6), edge computing and swarm intelligence (→4.3.4) can be of help when it comes to using large volumes of data efficiently without compromising data privacy and having to rely on centralized datasets.

Encouraging voluntary and participatory engagement, as well as creative efforts to acquire individuals' consent to share their data can help promote data-sharing (WHO 2021a). To enable the secondary use of health data in research and partnerships pursued among various institutions and actors, the creation of relevant interfaces and interoperability for products like the electronic health records (EHR) must be supported. Establishing such capabilities can prove useful, particularly when it comes to validating and benchmarking AI solutions, for example (WHO 2021b). Sustainable development goal considerations (European Health Data Space), such as the need to reduce and optimize algorithmic systems' energy and resource consumption should be integrated into decisions regarding government investment in the data economy (Data Ethics Commission 2019).

On their way to becoming a tool within the German healthcare system, Digital Health Applications (DiGAs) are now available as a benefit covered by statutory health insurance. One of the eligibility prerequisites stipulated by the Digital Healthcare Act (DVG) is that such applications serve to detect, monitor, treat or alleviate an illness, injury or disability. Applications designed to help prevent disease, however, are not recognized as a DiGA. Given the considerable health benefits and economic potential offered by preventive medicine, it would be prudent to expand the list of eligible applications to include those targeting prevention. It would also be advisable to expand the pool of those with access to tech giants' data to include other researchers and companies so that they, too, can develop innovative applications.

5 Advance risk-adapted regulation of artificial intelligence in the EU

The European Union should enable and regulate a sufficiently differentiated, risk-appropriate approach to AI systems (Data Ethics Commission 2019) and thereby ensure that innovation in this area is not inhibited, but fundamental rights and freedoms – such as human dignity, self-determination, privacy, equal treatment and personal integrity – remain protected (European Commission April 21, 2021). Analogous to the European General Data Protection Regulation (GDPR), this regulation should also cover products and applications that companies based outside the European Union develop or use in the EU. It would thus also affect the relevant activities of tech giants in healthcare and other sectors.

The goal here is to ensure a safe and non-discriminatory use of AI that promotes rather than destroys public trust in technological innovation and which allows for meaningful human control even in cases involving highly automated algorithmic systems. Ideally, this regulation would include enforcing minimum standards in an ethics-by-design approach.

6 Incorporate an ethics-by-design approach into the design, development and use of AI systems

Ethical considerations should be incorporated into the development of algorithmic systems from the outset. In line with the ethics-by-design approach,[134] so-called ethical requisites are "baked in" to the development of a technological model, which involves proactively applying moral principles throughout the process of development and deployment (WHO 2021a; Brey and Brandt 2020). The approach can be viewed in terms of a five-layer model, from the more abstract to the more specific: (1) ethical values that must be upheld and enhanced, not violated; (2) ethical requisites as conditions to be met by the system in terms of it embodying specific values through, for example, its functionality and data structures; (3) ethics-by-design guidelines for individual steps in development processes; (4) ethical principles are mapped on to the various components of individual AI methodologies used in development; (5) tools and methods that are aligned with ethical requisites independently of AI methods used in the development community (Brey and Brandt 2020: 9).

If an ethics-by-design approach is incorporated into the development of AI systems in the healthcare sector, this should be reflected in both European and national approval and certification procedures for new applications and products. The approach should also be taken into account in risk-adequate AI regulation. Similarly, given the intensive use of energy and resources involved

134 See, among others, the SHERPA Project, the SIENNA Report, and the expert opinion of the Data Ethics Commission (Brey et al. 2021; Brey and Brandt 2020; High-Level Expert Group on AI 2021; Data Ethics Commission 2019).

in the development of AI technologies and in accordance with the United Nations' Sustainability Development Goals (UN 2015) (➔4.2.7), environmental sustainability requirements must also be drafted that apply to the tech giants as well. Potentially helpful examples include requiring companies to disclose their energy footprints[135] and directing public funds toward AI-based systems designed to track environmental impacts and the optimization of resource use (van Wynsberghe 2021; Data Ethics Commission 2019). In addition, the development and use of AI models must be proportionate to their purpose,[136] and models should be designed, for example, that use smaller, carefully screened datasets and thus reduce their carbon footprint (WHO 2021a).

7 Legally prohibit the use of health-related risk profiles to discriminate in non-healthcare settings

Legal regulations should be created to prevent health-related data – and the risk profiles generated by them – from being used in areas unrelated to healthcare or medical research in ways that are inappropriate, discriminatory, manipulative, or otherwise violate the integrity of the personality. This could involve for example, prohibiting the use of such profiles in job searches or when purchasing life insurance (➔4.3.1). This requires defining the legal provisions for prohibiting exploitation, for example, within the context of the EU anti-discrimination directive (2004/113/EG) and according national legislation.[137] In order to protect personal integrity, limits should also be placed on the creation of risk profiles for various aspects of life without the consent of the individual from whom the data originated (Data Ethics Commission 2019).

According to expert commissions, in order to protect health data and health-related risk profiles while at the same time promoting the use of data for science and research and development, a regulation "regulating the use of sector-specific health data" would be helpful (SVR 2021: XXVIII). The goal is to agree on a common legal and technical framework for the secondary use of data among EU countries in cross-border health research (ibid.) In addition, it should be examined "whether the possibility of processing on a legal basis without a consent requirement or opt-out option can be created for healthcare data that are considered particularly relevant for health research, as is possible under European law on the basis of Article 9 (2) of the GDPR" (SVR 2021: 232). Such legislation could also involve specifying regulations for the handling and sharing of data on the part of the tech giants, thus counteracting their monopoly-like position.

135 Emissions from different technological systems can be calculated and compared in an effort to reduce carbon emissions (van Wynsberghe 2021; Strubell et al. 2019). Lacoste et al. (2019) proposed the Machine Learning Emissions Calculator for this purpose, Henderson et al. (2020) developed an experiment-impact-tracker framework, and Anthony et al. (2020) built on this to develop the Carbon Tracker. Establishing or even mandating such calculation processes in technology development, carbon emissions and impacts can be made transparent and thus factored into the development process.

136 Institutions such as the European Commission should develop a "proportionality framework" for assessing whether the training and tuning of an AI model is proportional to its carbon footprint (van Wynsberghe 2021).

137 General Act on Equal Treatment (AGG) of August 8, 2006, BGBI I: 1897, 1910; as amended on April 3, 2013, BGBl I: 610.

8 Develop a strategy for a learning healthcare system

To implement technologies in healthcare, policymakers should draft a strategy to establish a learning healthcare system. This includes creating a multilevel governance framework that ultimately enables and promotes a cycle of learning in which data from everyday medical care are subject to scientific analysis and then rapidly incorporated into efforts to improve care. This should involve taking a multistakeholder approach and launching initiatives that draw on financial, organizational, human and technological resources (WHO 2021b; UN Secretary-General's High-level Panel on Digital Cooperation 2019). In addition to governments and politicians, representatives from civil society, the research community, industry and business should also be brought into the process, as well as other groups thus far excluded from the discourse, such as older people, people with disabilities, the chronically ill, rural populations and indigenous groups or people with a migrant background (UN Secretary-General's High-level Panel on Digital Cooperation 2019).

The political actors and self-governing corporatist bodies involved in multilevel governance should remain mindful of ethical requirements such as data protection, security, the protection of privacy and personal integrity, freedom of research and protections against discrimination (WHO 2021b). Efforts targeting these issues have the capacity to facilitate the creation of a learning healthcare system that engages all healthcare actors in advancing knowledge and which can harness the tech giants' potential in ways that prove beneficial to society as a whole.

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