Major Computing Technologies of the Past 75 Years

By: Nir Kshetri and Jeffrey Voas

Kshetri, Nir, and Voas, J. (2021). "Major Computing Technologies of the Past 75 Years", IEEE *Computer,* The IEEE Computer Society's 75th Anniversary Celebration.54(5), 15-21. https://doi.org/10.1109/MC.2021.3058022

Abstract:

This article is the second in a series of four articles that Computer is publishing to celebrate the 75th anniversary of the IEEE Computer Society (CS) this year. The first article published in the February 2021 issue gave an overview of socioeconomic transformations facilitated by computing technology during the past 75 years and looked at some of the key roles played by the CS to enable this change. 1 In this article, we look at the major computing technologies enabling such transformations.

Keywords: IEEE Computer Society | computers | history

Article:

This article is the second in a series of four articles that *Computer* is publishing to celebrate the 75th anniversary of the IEEE Computer Society (CS) this year. The first article published in the February 2021 issue gave an overview of socioeconomic transformations facilitated by computing technology during the past 75 years and looked at some of the key roles played by the CS to enable this change.[1] In this article, we look at the major computing technologies enabling such transformations.

These computing technologies can be roughly divided into two categories: those driving the Third Industrial Revolution (3IR) and the Fourth Industrial Revolution (4IR). The distinction, however, is not clear cut because the 3IR has not yet reached its maturity.[2] Some view the 4IR as a continuation of the 3IR.

In the 3IR, computers and communication technologies facilitated the evolution of the digital age. The main drivers of the 4IR are disruptive computing technologies such as 3D printing, 5G telecoms, augmented reality, artificial intelligence (AI), autonomous vehicles, blockchain, big data, digital twins (DTs), Internet of Things (IoT), quantum computing, remote sensing, robotics (including collaborative robots or cobots), and wearables. In Table 1, we summarize brief histories as well as current and future situations and trends associated with some of these technologies.

Table 1. A brief history and current and future situation and trends of major computing technologies of the past 75 years.

Technology	Origin/brief history	Current and future situation and trends
Computers including minicomputers and personal computers	1944: Harvard Mark I and Colossus were launched 1960: The first minicomputer, PDP-1, was released by Digital Equipment corporation[15] 1971: the first personal computer Kenbak I was launched 1975: The term "personal computer" is coined[46]	2020: The world's fastest supercomputer Fugaku'a performance level: 442,010 teraflops 2019: 47.1% of households worldwide had a computer
Internet	1969: The Arpanet was started August 1991: The World Wide Web became publicly available	31 December 2020: 4.95 billion people online IP traffic: more than 45,000 GBPS in 2017, 150,700 GBPS by 2022[16]
Cell phones and cellular mobile networks	1973: DynaTAC 8000x was launched by Motorola 1983: DynaTAC 8000x was marketed	5G users worldwide: fewer than 200 million in 2019, 1.02 billion in 2023 and 3.5 billion in 2026[16]
Cloud computing	1996: Executives of Compaq Computer first used the term 2006: Large companies started offering cloud computing	2025: 49% of stored data will be in public clouds (IDC's estimate) Barracuda Networks: 45% of IT infrastructure used by companies was in the public cloud in 2020 and is expected to increase to 76% by 2025
Big data	2001: The formal definition was proposed by Gartner	IDC: The size of the Global DataSphere 33 ZB, over 59 ZB in 2020 and expected to reach 175 ZB by 2025
Internet of Things	1990: The first IoT device—a toaster—was controlled with a computer 1999: The term "Internet of Things" was first coined	Number of IoT devices: 14.2 billion in 2019, 25 billion in 2021, 64 billion in 2025
Artificial intelligence	The term was first used in 1956 Machine learning was first defined in 1959	AI spending: US$37.5 billion in 2019, expected to reach US$58 billion by 2021 and US$97.9 billion in 2023
Blockchain	2008: Satoshi Nakamoto published a white paper on a decentralized peer-to-peer electronic cash system (Bitcoin) 2009: The first Bitcoin block was mined[18]	PwC: blockchain will boost the global GDP by US$1.76 trillion by 2030[17] Main areas likely to be impacted: provenance, US$962 billion; payments and financial services, US$433 billion; identity management, US$224 billion; contracts and dispute resolution, US$73 billion; customer engagement, US$54 billion
DT	2002: NASA became the first organizations to formally use the concept of DTs	The global DT market size: US$3.1 billion in 2020, predicted to reach US$48.2 billion by 2026

Computers, Including Minicomputers and Personal Computers

The Harvard Mark I computer, which was a general-purpose electromechanical computer built at Harvard University and considered to be the first in the era of modern computers, was launched in 1944, two years before the formation of the Subcommittee on Large-Scale Computing Devices of the American Institute of Electrical Engineers, the predecessor organization of the cs.[19] The first large-scale electronic computer, Colossus, also started its operation the same year.[20]

The early models of computers were extremely slow compared to today's standards. The Mark I computer was capable of doing only three additions or subtractions per second. A multiplication and a division took 6 s and 15.3 s, respectively. More complex functions such as logarithm and

trigonometric functions took over 1 min.[25] Contrast this with the world's fastest supercomputers in 2020 Fugaku, which was built by Fujitsu for Japan's RIKEN Center for Computational Science. Fugaku's performance level was 442,010 teraflops per second on the Linpack benchmark.[28]

Kenbak Corporation launched Kenbak I computer, described as the first personal computer by the Boston Computer Museum.[3] The price was US$750, which amounted to an inflation adjusted price of US4,659 in 2018. The price of computer chips has been falling rapidly, which has made PCs highly affordable and available. As of January 2021, some Chromebooks, which run the Chrome operating system, were available for fewer than US$200.[23] As of 2019, 47.1% of households worldwide had a computer.[24]

The Internet

Among the most significant events in the history of the Internet was the establishment of the Advanced Research Projects Agency Network (Arpanet) in 1969 by the U.S. Defense Department.[27] It was the forerunner of today's Internet. Many protocols developed by the Arpanet are used in today's Internet. The World Wide Web became publicly available in August 1991.[29]

Due to significant advancements in computing and communication technologies, the Internet has experienced a rapid growth in terms of the number of people online as well as the flow of data across the Internet. As of 31 December 2020, 4.95 billion people or 63.2% of the world's population were online.[32] It is estimated that 90% of the world's population over six years of age will be online by 2030.[21] In 1992, the flow of data across the Internet or the IP traffic was about 100 GB per day. It increased to more than 45,000 GB/s by 2017, which is expected to reach 150,700 GB/s by 2022.[16]

Cell Phones and Cellular Mobile Networks

The history of cell phones and cellular mobile networks started in 1973, when a prototype of the first handheld cellular telephone DynaTAC 8000x was launched by Motorola. It weighed 2.5 lb and had a single-line, text-only LED screen.[22] In 1983, the portable mobile phone DynaTAC 8000x, which was small enough to carry, was marketed.[22] It weighed 28 ounces (790 g) and was 10 inches (25 cm) high.[26]

In 1991, 2G cell phones, which replaced the analog 1G technology, became available to consumers, and 3G and 4G cell phones were launched in 2001 and 2009, respectively.[26]

Cell phones and cellular mobile networks are widely available worldwide (Figure 1). There were about 8.2 billion mobile cellular telephone subscribers worldwide in 2020.30 According to the statistics portal Statista, there are 3.8 billion smartphone users worldwide.[31] Cell phones and cellular mobile networks especially are a game changer for developing economies, which have presented an opportunity to leapfrog. Developing economies had a cell phone penetration rate of 99.3% in 2020.[33]

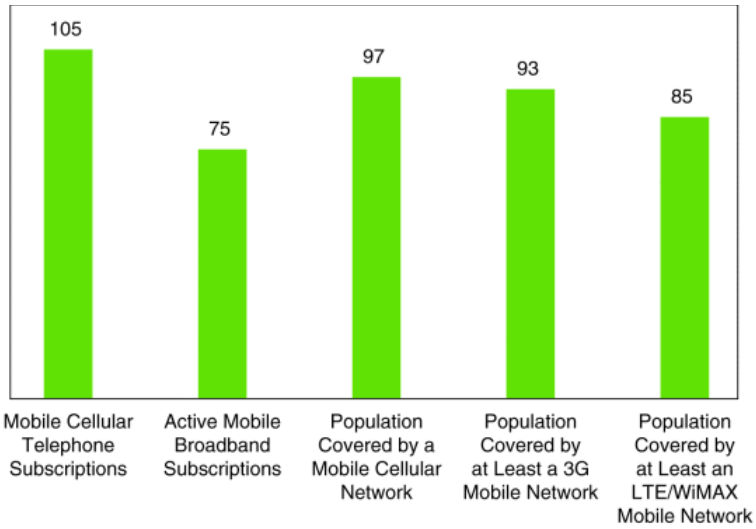

Figure 1. Percentage of the world's population subscribing to or covered by cell phones and cellular mobile networks. (Data source: The International Telecommunication Union.)

The latest generation of wireless technology, 5G, was launched in 2019. The number of 5G users worldwide was fewer than 200 million in 2019, but that number is expected to increase to 1.02 billion in 2023 and 3.5 billion in 2026.[35]

Cloud Computing

Technology Review attributes the origination of the term cloud computing to a group of technology executives of Compaq Computer (which was acquired by Hewlett-Packard), which first used the term in 1996. In 2006, large companies such as Google and Amazon started offering cloud computing. In the new paradigm, individuals and organizations started accessing software, computer power, and files over the Internet instead of storing all of this on their desktops.[4]

The adoption of the cloud is rapidly increasing among businesses and individuals. According to the security firm Barracuda Networks' study, 45% of IT infrastructure used by companies was in the public cloud in 2020, which is expected to increase to 76% by 2025.[5] Likewise, an estimate released by International Data Corporation (IDC) suggests that by 2025, 49% of the world's stored data will be in public clouds.[39]

Big Data

Advancements in telecommunications and computer technologies and the associated reductions in costs have led to an exponential growth and availability of data, both in structured and unstructured forms. Organizations found that conventional databases as the primary means of handling data are no longer useful. Since the 1990s, the term "big data" has been used to describe visualization and other challenges associated with the huge amount of data that require distinct tools and management approaches. A formal definition of the term was proposed by Gartner, Inc. in 2001. Gartner defined big data as data in high volumes with greater variety and arriving with ever-higher velocity.[36]

According to the IDC, the size of the Global DataSphere or the amount of data created, captured, and replicated in the world was 33 ZB in 2018 and over 59 ZB in 2020, and is expected to reach 175 ZB by 2025.[39,40]

Internet of Things

In 1990, the founder of FTP Software, John Romkey, created the first IoT device—a toaster, which could be controlled with a computer. In 1999, Kevin Ashton, consumer sensor expert and executive director of the Auto-ID Center, first coined the term "Internet of Things."[43] Currently there are tens of billions of IoT devices, such as home routers, webcams, digital video recorders, and other appliances with Internet capabilities built into them that provide diverse functionalities. The number of IoT devices worldwide was estimated at 14.2 billion in 2019, which is expected to increase to 25 billion in 20216 and 64 billion in 2025.[7]

Artificial Intelligence

The term "artificial intelligence" was first used by John McCarthy in 1956, who defined it as "the science and engineering of making intelligent machines."[45] Likewise, machine learning was first defined in 1959 by Arthur Samuel as a "field of study that gives computers the ability to learn without being explicitly programmed."[34]

AI is used in diverse contexts and areas such as driverless cars in the auto industry, organizing operations and reducing frauds in the financial industry, identifying correct medications and medical issues even before they present themselves in the health care industry, and delivering better advertising in marketing.[37]

According to IDC, AI spending was US$37.5 billion in 2019.[38] It will reach US$58 billion by 2021 and US$97.9 billion in 2023.[41,42]

Blockchain

First introduced in 2008, blockchain was implemented as the infrastructure of the cryptocurrency Bitcoin in 2009 by the pseudonymous person(s) Satoshi Nakamoto. Blockchain-based applications are the result of advancements in multiple technologies and concepts such as peer-to-peer networking, cryptographic hash functions, digital signatures, and game theory.

The multinational professional services firm PricewaterhouseCoopers (PwC) expects that blockchain will boost the global GDP by US$1.76 trillion by 2030.[44] PwC identified traceability and provenance as the number one use case of blockchain.[8] Payments and settlement, identity management and verification, supply chain management, fraud prevention and compliance, and asset tokenization have been other key application areas for blockchain.[9]

DTs

NASA, which is a U.S. federal government agency responsible for civilian space programs, aeronautics, and space research, was among the first organizations to formally use the concept of DT in 2002.[46] A physical entity's DT, which provides a virtual representation of and describes the product accurately both at micro as well as macro levels, is providing a number of benefits in diverse industries.[10]

Due to falling costs of storing and transmitting data and advances in AI, machine learning, big data analytics, IoT, and other areas, it is becoming feasible to develop and implement DTs in many settings. The global DT market size was estimated at US$3.1 billion in 2020, which is predicted to reach US$48.2 billion by 2026.[49]

In the past 75 years, a number of computing technologies with significant economic and societal promise and benefits originated and evolved. For instance, AI is arguably the fundamental technology of the 4IR.[11] Economists view AI as among the four most important "general purpose technologies" (GPTs),[12] the other three being steam engine, electric power, and IT. GPTs possess the potential to transform household as well as business activities.[13] GPTs such as AI also facilitate complementary innovations and bring transformations and changes in business processes.[12] Likewise, cloud computing is likened and equated to the industrial revolutions in terms of implications for technological innovations and economic growth.

The confluence and convergence of these technologies have made it possible to take actions and make decisions that can have a profound impact on our economy, health and well-being, environment, and social relations. Combined together, these technologies have broader and more powerful impacts. For instance, the convergence of a number of trends, such as innovations in low-cost devices and sensors, scalable network connectivity, and maturity of mobility, cloud, and big data models, has increased the attractiveness of IoT.

CS has highlighted the key aspects of these computing technologies and the most recent trends, applications, and prospects in these fields by publishing articles in its magazines and transactions and organizing symposiums, workshops, and conferences. For instance, the minicomputer market started to grow in the 1960s and expanded rapidly in the early 1970s (Table 1).[48]

The symposium Minicomputers—Trends and Applications was organized on 1 March 1972 by the CS's Eastern Area Committee and Washington, D.C. Chapter. The conclusions and outcomes of the symposium were reported in May/June 1972 issue of *Computer*. Additional articles on minicomputers published by *Computer* included "The Applications of Minicomputers" (September/October 1971) and "Minicomputers in the Digital Laboratory Program" (January/February 1973).

Likewise, when large companies started offering cloud computing, *Computer* provided insights into the readiness of cloud computing to transform economies, industries, and business models by publishing articles such as "Is Cloud Computing Really Ready for Prime Time?" (January 2009), "Cloud Computing for Mobile Users: Can Offloading Computation Save Energy?" (April 2010), and "Cloud Computing in Developing Economies" (October 2010).[14] More recently, several articles published in *Computer*, such as "Blockchain and Cyberphysical Systems" (September 2020) and "Artificial Intelligence and Critical Systems: From Hype to Reality"

(November 2020), have provided important new insights into disruptive computing technologies such as AI and blockchain.

IEEE's first-ever digital library, CS Digital Library's (CSDL) made up of 33 magazines and transactions and more than 600,000 articles, extensively covers key technological developments of the past 75 years.[47] These publications provide resources to understand computing technologies related to 3IR and 4IR such as big data, cloud computing, AI, smart systems, mobile, and wearables. CS also publishes specialized journals, transactions, and magazines focusing exclusively on specific computing technologies such as big data (*IEEE Transactions on Big Data*) and cloud computing (*IEEE Transactions on Cloud Computing*).

References

1. N. Kshetri, J. Voas, and R. Sharma, "Computing and socio-economic transformations," *Computer*, vol. 54, no. 2, pp. 26-29, Feb. 2021. doi: 10.1109/MC.2020.3038410.
2. J. Duncan. "What can the Fourth Industrial Revolution learn from the Third Industrial Revolution?" Daily Maveric. 2019. https://www.dailymaverick.co.za/article/2019-07-25-what-can-the-fourth-industrial-revolution-learn-from-the-third-industrial-revolution/ (accessed Mar. 26, 2021).
3. E. Comen. "Check out how much a computer cost the year you were born." USA Today. June 22, 2018. https://www.usatoday.com/story/tech/2018/06/22/cost-of-a-computer-the-year-you-were-born/36156373/
4. A. Regalado. "Who coined 'Cloud Computing'?" Technology Review. Oct. 31, 2011. https://www.technologyreview.com/2011/10/31/257406/who-coined-cloud-computing/#:~:text=The%20notion%20of%20network%2Dbased,term%20to%20an%20industry%20conference
5. L. Ingham. "Public cloud will be home to 76% of IT infrastructure by 2025, but security concerns remain." Verdict. 2020. https://www.verdict.co.uk/public-cloud-security/
6. G. Omale. "Gartner identifies top 10 strategic IoT technologies and trends." Gartner. 2018. https://www.gartner.com/en/newsroom/press-releases/2018-11-07-gartner-identifies-top-10-strategic-iot-technologies-and-trends
7. P. Newman. "IoT report: How Internet of Things technology growth is reaching mainstream companies and consumers." Business Insider. 2019. https://www.businessinsider.com/internet-of-things-report
8. "Time for trust: The trillion-dollar reasons to rethink blockchain." PWC. 2020. https://image.uk.info.pwc.com/lib/fe31117075640475701c74/m/2/434c46d2-a889-4fed-a030-c52964c71a64.pdf
9. N. Kshetri, *Blockchain and Supply Chain Management*. Cambridge, MA, Elsevier, 2021.
10. N. Kshetri, "The economics of digital twins," *Computer*, vol. 54, no. 4, pp. 86–90, 2021.

11. C. Herweijer and D. Waughray. “Fourth Industrial Revolution for the earth harnessing artificial intelligence for the earth.” PWC. 2018. https://www.pwc.com/gx/en/sustainability/assets/ai-for-the-earth-jan-2018.pdf

12. I. Gill. “Whoever leads in artificial intelligence in 2030 will rule the world until 2100.” Brookings. 2020. https://www.brookings.edu/blog/future-development/2020/01/17/whoever-leads-in-artificial-intelligence-in-2030-will-rule-the-world-until-2100/

13. B. Jovanovic and P. Rousseau, “General purpose technologies.” The National Bureau of Economic Research. 2005. https://www.nber.org/papers/w11093

14. N. Kshetri. “Cloud computing in developing economies,” *Computer*, vol. 43, no. 10, pp. 47–55, 2010. doi: 10.1109/MC.2010.212.

15. “History of computers.” Sutori. https://www.sutori.com/item/1960-the-pdp-1-the-first-mini-computer-released-by-digital-equipment-corporation (accessed Jan. 15, 2021).

16. “Global efforts needed to spread digital economy benefits, UN report says,” United Nations Conference on Trade and Development, Geneva, Sept. 2019. [Online]. Available: https://unctad.org/news/global-efforts-needed-spread-digital-economy-benefits-un-report-says

17. “Blockchain technologies could boost the global economy US$1.76 trillion by 2030 through raising levels of tracking, tracing and trust.” PricewaterhouseCoopers. https://www.pwc.com/gx/en/news-room/press-releases/2020/blockchain-boost-global-economy-track-trace-trust.html (accessed Jan. 15, 2021).

18. “History of blockchain.” Binance. https://academy.binance.com/en/articles/history-of-blockchain (accessed Jan. 15, 2021).

19. “The 1950s and 1960s.” IEEE Computer Society. https://www.computer.org/about/cs-history/1950-1969 (accessed Jan. 15, 2021).

20. B. J. Copeland, “Colossus.” Britannica. https://www.britannica.com/technology/Colossus-computer (accessed Jan. 15, 2021).

21. “Humans on the internet will triple from 2015 to 2022 and hit 6 billion.” Cybercrime Magazine. https://cybersecurityventures.com/how-many-internet-users-will-the-world-have-in-2022-and-in-2030/ (accessed Jan. 15, 2021).

22. G. Blazeski, “Martin Cooper invented the mobile phone in 1973. Was inspired by Star Trek.” The Vintage News. https://www.thevintagenews.com/2016/10/16/priority-martin-cooper-invented-mobile-phone-1973-says-inspired-captain-kirks-gold-flip-top-communicator-star-trek/ (accessed Jan. 15, 2021).

23. “The best budget laptops.” Business Insider. https://www.businessinsider.com/best-cheap-laptop (accessed Jan. 15, 2021).

24. “Statistics,” International Telecommunication Union. https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx (accessed Jan. 15, 2021).

25. “WWII, Grace Hopper with Harvard Mark 1 Computer, 1944.” Science Source. https://www.sciencesource.com/asset-management/2OPEBM9J6Y3A?FR_=1&W=1366&H=625 (accessed Jan. 15, 2021).

26. “Motorola (cellphone).” First inversion. https://www.firstversions.com/2015/01/motorola.html (accessed Jan. 15, 2021).

27. “Internet history timeline: ARPANET to the World Wide Web.” LiveScience. https://www.livescience.com/20727-internet-history.html#:~:text=The%20precursor%20to%20the%20Internet,used%20for%20Internet%20communication%20today (accessed Jan. 15, 2021).

28. S. Fulton. “Top500: Japan’s Fugaku Still the World’s Fastest Supercomputer.” DataCenter Knowledge. https://www.datacenterknowledge.com/supercomputers/top500-japan-s-fugaku-still-world-s-fastest-supercomputer (accessed Jan. 15, 2021).

29. M. Bryant. “20 years ago today, the World Wide Web opened to the public.” The Next Web. https://thenextweb.com/insider/2011/08/06/20-years-ago-today-the-world-wide-web-opened-to-thepublic/#:~:text=On%206%20August%201991%2C%20the,know%20what%20the%20Internet%20was.&text=The%20WWW%20project%20merges%20the,but%20powerful%20global%20information%20system (accessed Jan. 15, 2021).

30. “Artificial intelligence.” Science-Daily. https://www.sciencedaily.com/terms/artificial_intelligence.htm (accessed Jan. 15, 2021).

31. “Number of smartphone users worldwide from 2016 to 2023.” Statista. https://www.statista.com/statistics/330695/number-of-smartphone-users-worldwide/ (accessed Jan. 15, 2021).

32. “Internet usage statistics: The internet big picture.” Internet World Stats. https://www.internetworldstats.com/stats.htm (accessed Jan. 15, 2021).

33. “What is a digital twin and why it matters.” Honeywell, Nov. 21, 2019. https://www.honeywell.com/us/en/news/2019/11/what-is-a-digital-twin (accessed Jan. 15, 2021).

34. “Machine learning is moving into the mainstream thanks to advances in processing power, deep learning, and big data.” Eurpeople. https://www.eurpeople.com/machine-learning-goes-mainstream/ (accessed Jan. 15, 2021).

35. “Introducing 5G technology and networks (speed, use cases and rollout).” Thales. https://www.thalesgroup.com/en/markets/digital-identity-and-security/mobile/inspired/5G#:~:text=Globally%2C%20the%20number%20of%205G,2020 (accessed Jan. 15, 2021).

36. “Big data defined.” Oracle. https://www.oracle.com/big-data/what-is-big-data.html (accessed Jan. 15, 2021).

37. Baystreet Staff. “Here’s why investors should pay close attention to artificial intelligence.” Baystreet, Jan. 20, 2021. https://www.baystreet.ca/stockstowatch/9558/Heres-Why-Investors-Should-Pay-Close-Attention-to-Artificial-Intelligence (accessed Jan. 15, 2021).

38. “Worldwide spending on artificial intelligence systems will be nearly $98 billion in 2023, according to new IDC spending guide.” IDC, Sept. 4, 2019. https://www.idc.com/getdoc.jsp?containerId=prUS45481219 (accessed Jan. 15, 2021).

39. D. Reinsel, J. Gantz, and J. Rydning, “The digitization of the world: From edge to core,” IDC, Needham, MA, White Paper, Nov. 2018. Accessed Jan. 15, 2021. [Online]. Available: https://www.seagate.com/files/www-content/our-story/trends/files/idc-seagate-dataage-whitepaper.pdf

40. “IDC’s global datasphere forecast shows continued steady growth in the creation and consumption of data,” IDC, May 8, 2020. https://www.idc.com/getdoc.jsp?containerId=prUS46286020 (accessed Jan. 15, 2021).

41. “IEEE Computer Society Digital Library (CSDL).” IEEE. https://www.ieee.org/about/ieee-india/ieee-computer-society-india/csdl.html (accessed Jan. 15, 2021).

42. “Minicomputers.” Encyclopedia.com. https://www.encyclopedia.com/computing/news-wires-white-papers-and-books/minicomputers (accessed Jan. 15, 2021).

43. A. Pardes. “The WIRED guide to the Internet of Things.” Wired, Nov. 9, 2020. https://www.wired.com/story/wired-guide-internet-of-things/ (accessed Jan. 15, 2021).

44. “$48.2 billion digital twin markets: aerospace & defense, automotive & transportation, healthcare - Global Forecast to 2026—Research-And-Markets.com.” Yahoo Finance, Nov. 20, 2020. https://finance.yahoo.com/news/48-2-billion-digital-twin-133900362.html (accessed Jan. 15, 2021).

45. B. Borgobello. “Looking back on 40 years of the cell phone.” New Atlas, Jan. 25, 2013. https://newatlas.com/mobile-pnone-40-year-anniversary-photos/25677/ (accessed Jan. 15, 2021).

46. G. Wittenburg, “The minicomputers of the 70s,” Inst. Computer Sciences, FU Berlin, 2001. Accessed Jan. 15, 2021. [Online]. Available: http://www.inf.fu-berlin.de/lehre/SS01/hc/minicomp/