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Rolf Dornberger *Editor*

New Trends in Business Information Systems and Technology

Digital Innovation and Digital Business Transformation

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Preface

What is digital transformation? This question is often asked because no one knows what digital transformation and its impact on our lives are and will be in the future. Therefore, it is a highly demanding challenge to describe in detail what constitutes digital transformation.

The term *digital transformation* is often referred to as *digitalization* (not to be confused with *digitization*, the process of converting analog data into a digital counterpart). In this book, we use the word digitalization to describe the evolution process, in which digital technologies (meaning electronic, information, communication, etc. technologies) enable changes in business and society. These changes can range from continuous and smooth to erratic and disruptive.

On the one hand, new digital technologies are the drivers for changes in classical processes (e.g., text-processing software has made the old mechanical typewriters obsolete). On the other hand, a need for business or organizational processes is looking for the best available digital technology solution to overcome old processes (e.g., a suitable voice-over-IP protocol is in the process of replacing the traditional telephone transmission). In this book, in the first case, we call it *digital innovation*, in the second case, *digital business transformation*. In general, however, both tendencies are often interconnected and not so clearly separated. In order to provide a selection of the diversity of what digital transformation means for our daily lives, this book presents many different digitalization cases—some more focused on digital innovation and some on digital business transformation.

This book was written by professors and researchers who work, research, and teach daily in the areas of (Business) Information Systems, (Business) Information Technology, Computer Science, Business Administration and Management at the School of Business of the University of Applied Sciences and Arts Northwestern Switzerland FHNW. This university of applied sciences focuses on applied research and development while retaining a high level of practical relevance. Thus, the writing style of the chapters of this book follows the philosophy of reconciling the degree of depth and rigor in research with a meaningful translation into relevance in practice.

While the Institute for Information Systems of the School of Business originally focused on *bridging the gap between business and IT*, thus aligning business and IT in the context of organizations, its topics are now expanding extensively to cover a wider range of digitalization: The impact of new ICT-related technologies and IT-supported methods in business and society is investigated. In addition to the classic domains of business information technology, our areas of interest are, for example, agile process management in a digital economy, cloud computing and related digital transformations, cybersecurity and resilience, digital supply chain management, artificial intelligence including computational intelligence (i.e., nature-inspired AI) and symbolic/sub-symbolic AI, Internet-of-Things, human–machine interaction, (social) robotics, management of complex systems, humans in technical systems and organizations, etc. Our passion for the different facets of digitalization eventually led to the idea of writing this second book (after the Springer book “Business Information Systems and Technology 4.0” in 2018).

As the editor of the book, I would like to thank our employer, the University of Applied Sciences and Arts Northwestern Switzerland FHNW and particularly the School of Business for supporting the writing of the book by granting additional hours to the authors. My immense and heartfelt thanks also go to all our authors, who have made excellent contributions to this book with their view of digitalization. My special thanks go to Prof. Dr. Thomas Hanne, Prof. Dr. Uwe Leimstoll, and Prof. Dr. Michael von Kutzschenbach, who have organized a thorough and independent scientific peer review of all the chapters according to internationally recognized high quality standards. Additionally, I would like to thank Vivienne Jia Zhong for coordinating the process of elaborating the contributions of 42 authors, compiled in 21 chapters, efficiently and competently. I would also like to thank Christine Lorgé and Natalie Jonkers for their diligence, competence, and commitment to language and readability. Finally, I would like to thank all our families for their continued patience and great support in allowing us to write this book on weekends and during the night.

Basel, Switzerland Prof. Dr. Rolf Dornberger
January 2020

Contents

Digital Innovation and Digital Business Transformation in the Age of Digital Change

Rolf Dornberger and Dino Schwaferts

Abstract This chapter introduces the central theme of the book and the following chapters. In our book, we present 20 selected examples of digitalization in the age of digital change. The chapters are divided into two parts, called “Digital Innovation” and “Digital Business Transformation”. On the one hand, digital innovation includes cases where a new technology stimulates or enables new business opportunities. On the other hand, digital business transformation collects examples of digitalization in which business or management concepts exploit certain technological solutions for their practical implementation. To share this mind-set with the reader, quantum-computing technology will be taken as an example of digital innovation. This will be followed by reflections on digital business transformation, which seeks and uses digital technologies. Finally, the next chapters will be presented accordingly.

Keywords Digital innovation · Digital business transformation · Digitalization · Quantum computing · Digital eco-system

1 Introduction

It is widely predicted that digitalization will change the world. Already in 2018, the book “Business Information Systems and Technology 4.0: New Trends in the Age of Digital Change” [1] has presented selected cases which show how quickly the world changes and transforms. That book has provided explanations of key principles such as digitization, digitalization, and digital transformation. Therefore, the model in Fig. 1 “Digitalization: Yesterday, today and tomorrow” [2] was introduced. This

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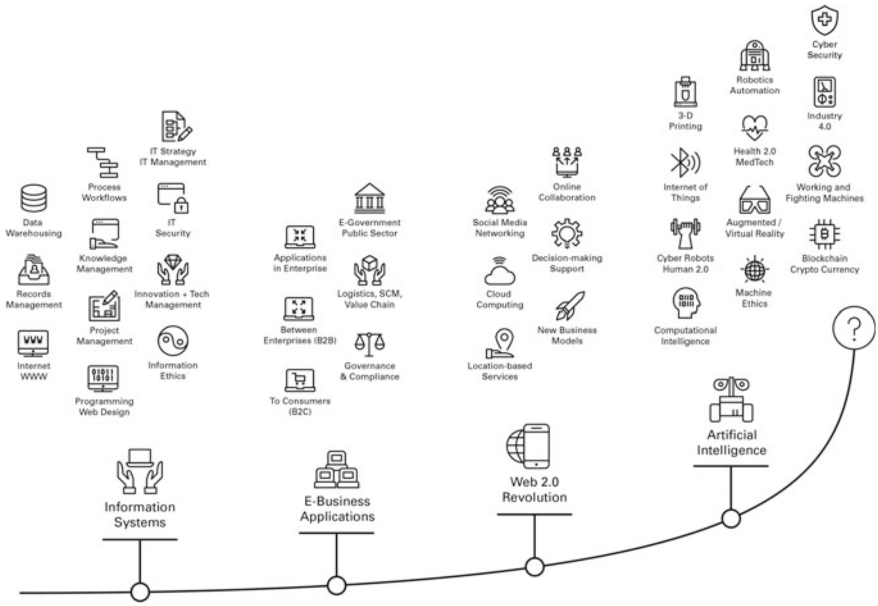

Fig. 1 Digitalization: yesterday, today and tomorrow [2]

model discusses the development of the information and communication technology over four stages: The sequence begins with (1) Information Systems in the 1980s and 1990s and (2) E-Business Applications in the late 1990s and early 2000s. In addition, the rise of web applications and smartphones from the mid to the end of the first decade of the 21st century, launched the (3) Web 2.0 Revolution. The sequence concludes with the renaissance of (4) Artificial Intelligence from the mid to the end of the second decade of the 21st century.

As illustrated in the model (see Fig. 1), the development of new digital technologies and applications seems to be growing exponentially (e.g., the number of digital technologies steadily increases; every year the number of scientific publications increases worldwide, etc. [3]). This implies that a vast amount of potentially world-changing innovations is constantly being generated. As examples, the authors stated in [1] that in addition to improvements in smarter software, new hardware devices are being created, such as robots and 3D printers, equipping the computers with a kind of a body and reshaping the supply chains. In parallel, the cyber-world is evolving, increasingly encompassing technologies such as virtual and augmented reality (VR/AR), which provide the interface to a digital or cyber world. Many aspects of the world are now becoming “cyber”. For example, cryptocurrencies are evolving and expanding established forms of money; and enhancing humans with artificial robotic body parts is no longer a distant dream.

This book goes a step further to provide new examples of how digital technologies and/or business opportunities created by digitalization cause innovation and transformation. It therefore builds on the model with the four stages discussed in [2], but also proposes the two aspects “Digital Innovation” and “Digital Business Transformation”, which cross-sectionally cover the four stages. Here, digital innovation means the use of new or existing digital technologies (from another context) to support certain aspects of management or business. However, digital business transformation is—according to Gartner [4]—“the process of exploiting digital technologies and supporting capabilities to create a robust new digital business model.”

To present and organize the subsequent chapters of this book, this introductory chapter briefly mentions the two aspects “digital innovation” and “digital business transformation”. The first aspect concerns a new technology (such as quantum computing) that is the starting point and enabler for new applications and business solutions. The second aspect concerns business/management ideas or concepts (such as digital eco-systems) that need digital technologies to support and implement them. As a guide for the readership of this book, all the ensuing chapters are briefly outlined and focus either on the first aspect “digital innovation” or the second “digital business transformation”.

2 The Technology of Quantum Computing as Digital Innovation

2.1 Identifying Promising Technologies

In order to predict whether and how a particular new digital technology can become a promising technology in the sense of enabling one of the most important digital innovations of the future, the important technologies to come must be continuously identified. The question often is: What will come next? In the model [2] in Fig. 1, many readers may wonder what the question mark on the rising curve means. Albert Einstein answered this question very elegantly by saying: “I never think of the future—it comes soon enough.”[1] According to this quote, the future seems to be approaching even faster today than in earlier times.

A well-known source and reference for future technologies and trends is the Gartner hype cycle for emerging technologies [5]. It proposes and discusses future technologies and trends in four phases:

1. Being a hype (peak of inflated expectations)
2. Producing a disappointment (trough of disillusionment)
3. Getting a realistic estimation (slope of enlightenment)
4. Leading to common application (plateau of productivity).

[1] https://quoteinvestigator.com/2013/07/23/future-soon/.

Once a new technology or trend appears on the hype cycle, it takes up a particular position on the cycle according to the estimation of its phase and in comparison to other technologies. Additionally, the predicted time until it becomes a common application is noted.

2.2 *Quantum Computing as an Example for Digital Innovation*

One technology that has been on the rising slope of the Gartner hype cycle for years is "quantum computing", which has appeared 11 times since 2000. In fact, Gartner predicted that quantum computing would reach its plateau of productivity in a maximum of five years or that over the next five to ten years it would be in general use. Thus, one can assume that the digital technology of quantum computing is an answer to the question mark in Fig. 1 and will become one of the next digital innovations. Why, however, will quantum computing become so important?

Quantum computing [6] is a novel ground-breaking mechanism for computing/processing units, leading to a new computer generation with an immensely higher computing speed. Its principles are based on the phenomena of quantum physics that can be used within a new type of central processing units inside a computer. While the theory is well developed, its realization in new hardware and software to take advantage of its full potential remains difficult. Currently, there is a handful of highly advanced research labs, which possess more or less well-running prototypes of quantum computers. However, there is still a chance that the realization of application-ready quantum-computing devices will not be possible in this century.

Assuming that ready-to-use quantum computing will be realized in the next years, one can say that it will change the world fundamentally. There will be a jump from today's "nice computing power" to "unbelievable, ultimate computing power", in which case the only limitations will be the computing memory and the available algorithms (software) to compute (almost) everything, known as Quantum Supremacy [7]. Some reflections below show why quantum computing is on the way to becoming such an important digital innovation—perhaps the most disruptive digital innovation of this century [8].

Bitcoin and similar cryptocurrencies will lose their motivation [9]. Theoretically, with quantum computing, all bitcoins will be instantly mined, because the computationally expensive computations for adding new blocks to the blockchain system will be carried out instantly. The miner (a specific role in the blockchain system) who gets first access to quantum computing will mine all bitcoins (perhaps introducing stupid transactions to generate new blocks with senseless back and forth transactions). Certainly, there are mechanisms, such as time delays that are integrated into the mining procedure; but today's standard ideas of generating particular cryptocurrencies (through computationally expensive blockchain computations) will have to be completely rethought.

In cryptography, quantum computing will break through almost any current encryption in no time [10]. Certainly, a new discipline will come into play called "quantum cryptography" that adapts and replaces outdated encryption algorithms. Nevertheless, in every encryption and decryption process, quantum computers will always be superior to traditional computing devices, even to today's supercomputers. For example, as cars exchange encrypted commands with their remote keys, it will allow hackers to use quantum computers to unlock not only one car, but also all other cars in the vicinity within a fraction of a millisecond.

DeepMind Technologies is a subsidiary of Alphabet Inc., the mother company of Google. The research of DeepMind focuses on different aspects of extending and applying Artificial Intelligence (AI). A showcase is the gameplay of the ancient Asian board game "Go". The projects AlphaGo, AlphaGo Zero, and Alpha Zero developed AI frameworks [11] that are (almost) always able to beat human world champions and other software in Go [12] and in various other kinds of single- and multi-player games [13]. DeepMind's AI approaches are superior to most other (published) approaches, including other software solutions, as well as to human gameplay strategies in games with (almost) infinite possible moves. The algorithms are special heuristics. Some of them are trained with huge human-generated datasets; some of them use self-training by generating own dataset by applying the game rules. These powerful heuristics search limited parts of the entire search space, where promising next moves seem favorable. However, a quantum computer may be able to search the entire search space (not only limited parts) and discover unknown sequences of moves that could even beat the best powerful heuristics. In other words, the ultimate quantum-computing power has great potential to further enhance today's best AI and decision-making algorithms—but also to make some AI approaches obsolete by instantly scanning the entire search space.

Another major application field in which quantum computing will have a tremendous impact, is modeling and simulation to be known as Quantum Simulation [14]. For example, the knowledge of how the universe, the solar system, and earth evolved over billions of years is still incomplete. Many details are still insufficiently understood. Today, different physical astronomical models and approaches are available to describe the development of the universe. Unfortunately, these models are still partially incompatible, and even supercomputers take weeks to compute results in well-selected sub-cases. Here, quantum computing will be able to compute different models with increasing granularity in almost no time. Then it will be possible to easily compare the results of the different models, improve the models, and gain an understanding about which models are best suited for different cases and how they fit together. In addition to astronomy, which takes place on the large scales (i.e. space and time), quantum computing will also help to understand the effects on the small scales, where quantum physics explores them.

Another discipline in which increased computing speed will have an extraordinary effect is engineering, which mostly uses search and optimization algorithms to computationally solve engineering problems [15]. In the last 40 years, numerical computations have already replaced various hardware tests and field experiments. Today, e.g., the most efficient engines, cars, and airplanes are developed and further optimized on the computer; prototype testing is reduced to a minimum. Furthermore, with quantum computing, it will be possible to simultaneously compute and compare millions of design variants. Each product is designed and optimized on the computer until optimal properties are reached. Then, because of myriads of computational optimization loops, all products of various companies will be quite similar. For example, washing machines, smartphones, and airplanes will be almost identical independently of the producing company. On the other hand, the differentiation will lie in the personalization of engineered products [16]. Users will get an optimal, personalized product that is tailored to their requirements, e.g., a personalized car (shape and size, engine, color, interior, etc.). Hundreds of personal choice features, including an optimized personal product design, can be integrated during the online configuration. Hence, quantum computing will create a new "personalized product business" [17].

Extending the idea of being able to design whatever is technically possible, we will also be able to research and develop new ways to preserve nature [18]. Ideally, we will be able to model, simulate, and optimize countless variants of environmental technologies and sustainable, renewable energy solutions. We will be able to find ways to reduce carbon dioxide emissions and other pollution markers. In addition, we will be able to better understand society as a living organism, and, in turn, enhance the living conditions of billions of people, merely by discovering new technologies and new ways for these solutions to influence the quality of life.

Certainly, all these examples of the benefits of quantum computing are very optimistic. However, as with any technology, quantum computing can also be used wrongfully, which we will not discuss here.

In summary, when digital technologies find their way to common applications, they are adopted as digital innovations. In this chapter, the technology of quantum computing was chosen as an example to explain how a new technology might stimulate many new applications and business opportunities, which is consequently called digital innovation. Later in the book in the Digital Innovation part, several chapters are collected to present specific technologies or technological approaches, which stimulate new applications, businesses, processes, or even thinking.

3 Leveraging Digital Business Transformation Through Digital Technologies

The section above describes the concept of digital innovation (used in this book to structure the upcoming chapters) using the example of quantum computing (i.e. how a digital technology might stimulate new applications). This section focuses on the possibility of realizing additional opportunities in business, management, learning, etc. by seeking and then exploiting new specific digital technologies. This is related to the already mentioned definition of digital business transformation [4] as "the process of exploiting digital technologies and supporting capabilities to create a robust new digital business model." However, the wording "business model" is used in a broader context, namely as "business, management or process opportunities", which can be realized, supported, and/or improved by seeking and exploiting suitable digital technologies. In the next section, some reflections are made about rethinking managerial approaches for business transformation in the age of digital change.

3.1 Rethinking Managerial Approaches for Business Transformation in the Age of Digital Change

When reflecting on the most important achievements of the industrial era around the 19th century, steam power, electrification, and the automobile could come to mind first. In parallel with the emergence of these new technologies, new management challenges also arose. According to the economic historian Pollard [19], current management approaches and topics have their origin in the emergence of large-scale organizations during the industrial era, where large companies were explicitly confronted with challenges on another extended scale. E.g. human resource management for mass employment, leadership and management of a big entity, huge financial issues, procurement and sales on a broad level, etc. Following Pollard, the origin of today's management approaches is strongly connected to the emergence of new technologies—in addition to various societal developments, ecological challenges and so forth.

Today, a new type of technology, namely the digital technologies, such as the Internet of Things (IoT), AI, Big Data, Cloud Computing, robotics, etc. have an impact on life and work [20] (e.g., all the IoT technology to be applied in Industry 4.0). Such a transition to a digital society and economy leads to different expectations towards management by both customers and employees. The question could be which new managerial approaches are emerging for business transformation in the age of digital change—to be reflected on in the next section and in the upcoming book chapters under the umbrella term "Examples for an increasing need for Digital Business Transformation".

3.2 About Examples in Digital Business Transformation

The following are some reflections on the particular state of companies and new possibilities offered by digital business transformation (i.e. the exploitation of digital technologies and supporting capabilities assisting company needs). The question is how digital technologies influence companies in the age of digital change.

Searching for management concepts and explanations of why companies in the industrial age are as they are, one might still refer to Coase [21], where he already asked in the 1930s, why and under what circumstances what kind of company would emerge. He concluded that a meaningful enterprise size and a special state of the company are the result of the balance between disadvantages from transaction costs and disadvantages from overhead costs, imperfection in resource allocation, and inflexibility. In the 70s and 80s of the last century, Porter [22] defined the state of a company by the concept of the value chain, where the value added performed in an organization determines the size and the condition of the company. However, around the year 2000, Porter added the influence of digitalization to his model, where the value added is now divided among different partners in a networked structure, which he calls "the system of systems". Examples in business are the automotive industry, which has long reduced its vertical integration, similar to early examples of virtual organizations, which have been building on this concept for more than 20 years [23].

In the age of digital change, the question arises: what exactly is the benefit of having the opportunity to exploit digital technologies to change the style of management and the state of companies? Can structures and processes be better defined to contribute more to the value creation? A particularly great opportunity that digital technologies offer today, is the simple division of tasks, the value chain, the management, the IT and so forth of every entity of the company (e.g., on the level of a project, a department or even the entire company). This means that many tasks—in terms of total value added—could now be divided and elaborated in different entities in parallel, fully supported by digital technologies. These entities could even lie outside the company, following the trend of focusing on one's own unique abilities. Each entity makes its own contribution to value creation by being connected and working together via digital technologies. Here, Porter's system of systems [22] with the flexible composition of services in the value chain and their orchestration or digital eco-systems [24] provide answers on how digitalization makes this possible [25].

Although these short reflections are only taken as an example in digital business transformation, it can be assumed that digital technologies have an important impact on management at various levels. Digital business transformation is strongly related, for example, to managerial approaches, the style of management, state of companies as well as to particular management topics (e.g. HR management or learning management) which are quickly changing nowadays. Therefore, it is indispensable to continuously investigate various upcoming management, business, societal demands, and further challenges in the search for digital technologies and solutions that support them. Selected topics are provided later in this book in the Digital Business Transformation part.

4 Organization of This Book

As explained above, this book consists of two parts, which represent the abovementioned topic fields, namely Digital Innovation and Digital Business Transformation, and which, in turn, compile the more technology-based topics and the more business/application-relevant topics. In the following, a very short description and a brief summary of the book chapters is given.

(a) Examples of emerging Digital Innovation (according to chapter order later in the book)

- Various digitization technologies have been researched for several years and optical character recognition (known as OCR) is nothing new. Nevertheless, an update with the latest machine-learning algorithms proves a new technological leap. "A Survey of State of the Art Methods Employed in the Offline Signature Verification Process" reviews the domain of offline signature verification and presents a comprehensive overview of methods typically employed in the general process of offline signature verification.
- When it comes to innovative idea generation, Design Thinking is mentioned as one of the most widespread and effective methods. However, in addition to all attempts to improve the design thinking processes, a sensible technological implementation and related scenarios, as discussed in "Agile Visualization in Design Thinking", promise a further innovative approach.
- In general, enriching classical algorithms with machine-learning approaches further improves their potential. An example is given in the text mining case "Text Mining Innovation for Business", reflecting on the business innovation enabled by developing text-mining solutions in response to the business needs of companies.
- The sensible use of embedded digital technologies can lead to new applications and generate digital innovations as shown in "Using Mobile Sensing on Smartphones for the Management of Daily Life Tasks", which explores the ability and the potential of the mobile-sensing technology to support daily life task management.
- The use of an advanced software solution in university education provides an advanced tutoring system. "A Dialog-Based Tutoring System for Project-Based Learning in Information Systems Education" presents and discusses the design of an intelligent dialog-based tutoring system that is designed to support students during group projects, to maintain their motivation and give subtle hints for self-directed discovery.
- However, it is often difficult to teach technologically advanced topics, for example object-oriented programming. In order to identify and evaluate the students' learning difficulties, a case of developing an assessment test is presented. "A Human Aptitude Test for Object-Oriented Programming in the Context of AI and Machine Learning" discusses the object-oriented programming paradigm and the potential future developments once AI and machine learning start to steadily increase their influence on the overall design of software systems.
- Methods that belong to AI tend to be among the more challenging subjects for students. A case of evaluating different measures to improve a related university course over ten years is discussed in order to propose best practices. "Adapting the Teaching of Computational Intelligence Techniques for Improving the Learning Outcomes" shows the continuous efforts to integrate nature-inspired AI, and in particular, computational intelligence algorithms into today's university teaching to increase the learning success of students.

- Some technologies force research to discuss them from the philosophical side. Maybe our view of technology is too strongly influenced by a too narrow perception of the world: We will see what we allow to be seen. “Automatic Programming of Cellular Automata and Artificial Neural Networks Guided by Philosophy” discusses an approach called “allagmatic method” that automatically programs and executes models with as little limitations as possible while maintaining human interpretability.
- Some technologies themselves are “hardcore”, like robots. They are a hype; they will change the world and businesses. “Facial Recognition and Pathfinding on the Humanoid Robot Pepper as a Starting Point for Social Interaction” examines the facial recognition and navigation capabilities of the robot Pepper and relates them to a better human-robot interaction.

(b) Examples for an increasing need to Digital Business Transformation (according to the chapter sequence later in the book)

- However, robots are not only a new hardware device with extended software capabilities. Organizations might have special process needs which best can be suited by involving and integrating robots. “Social Robots in Organizational Contexts: The Role of Culture and Future Research Needs” describes the organizational contexts currently relevant for social robots addressing the respective cultural challenges.
- Management must innovate and adapt in order to leverage the benefits of digitalization for a digitalized sustainability society. Here, “Digital Transformation for Sustainability: A Necessary Technical and Mental Revolution” outlines an integrated framework linking different levels of digitalness with necessary changes in managerial practice for organizational inquiry.
- Keeping humans-in-the-loop provides many advantages. For example, “Visualization of Patterns for Hybrid Learning and Reasoning with Human Involvement” discusses the traditional roles of humans in hybrid systems and their influence on machine learning and/or knowledge engineering activities.
- Learning can be improved by sensibly using selected technologies. Here, “Modeling the Instructional Design of a Language Training for Professional Purposes, Using Augmented Reality” presents a multi-layered instructional model for language training for professional adult learners.
- The processes in e-commerce are continuously improved by steadily integrating and using new technologies. “Frictionless Commerce and Seamless Payment” discusses a potential solution for improving the user experience and conversion optimization in e-commerce and provides existing practical examples.
- E-commerce has not necessarily led to disintermediation as predicted in the 1990s. “Direct to Consumer (D2C) E-Commerce: Goals and Strategies of Brand Manufacturers” suggests three strategies for brand manufacturers to mitigate conflicts with traditional sales partners while maintaining their presence on the Internet.

- Marketing is another management topic, where new technologies are highly appreciated to strengthen customer retention. "The Digital Marketing Toolkit: A Literature Review for the Identification of Digital Marketing Channels and Platforms" presents a study to support SMEs in their digital business transformation.
- Supply chain management also quickly adsorbs new technologies to improve its processes. "How the Internet of Things Drives Innovation for the Logistics of the Future" discusses an innovative value chain framework relating technology advancement to business innovation in logistics.
- Co-creation in networks is highly supported by digital technologies. As an example, "Recommendations for Conducting Service-Dominant Logic Research" addresses a research gap providing contextual guidance for applying service-dominant logic in research and a framework for innovation in business.
- Many recent business models rely on data as the most important asset, where data privacy is always an issue. "Blockchain Technologies towards Data Privacy—Hyperledger Sawtooth as Unit of Analysis" presents a study that provides insights for selecting a suitable blockchain configuration that would comply with regulatory data privacy requirements.
- "Leadership in the Age of Artificial Intelligence—Exploring Links and Implications in Internationally Operating Insurance Companies" describes a case that demonstrates the need (e.g., with the introduction of AI) for additional management approaches.

5 Conclusions

Everywhere, examples and good practices in the field of digitalization appear again and again, which aim to promise a change of the world, stimulated partly by new technologies, partly by business/management/societal needs, often by both. A promising way to identify possible next disruptive leaps in today's age of digital change is to continuously and profoundly explore a broad variety of examples. A small selection is shown in this book.

This chapter is intended to introduce the central theme of the book for the arrangement of the upcoming chapters grouped to two parts. Therefore, the aspect of Digital Innovation is introduced using the example of the upcoming digital technology of quantum computing that will most likely change the world. Then, the aspect of Digital Business Transformation is proposed and reflected as a change of management/business to exploit digital technologies. Finally, these insights are briefly mapped to the following book chapters, which—as will become obvious during the course of the book—show various new trends and challenges in the age of digital change from different perspectives. Maybe one of them will lead to the next disruptive leap in digitalization.

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Digital Innovation

A Survey of State of the Art Methods Employed in the Offline Signature Verification Process

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Abstract Handwritten signatures are of eminent importance in many business and legal activities around the world. That is, signatures have been used as authentication and verification measure for several centuries. However, the high relevance of signatures is accompanied with a certain risk of misuse. To mitigate this risk, automatic signature verification was proposed. Given a questioned signature, signature verification systems aim to distinguish between genuine and forged signatures. In the last decades, a large number of different signature verification frameworks have been proposed. Basically, these frameworks can be divided into online and offline approaches. In the case of online signature verification, temporal information about the writing process is available, while offline signature verification is limited to spatial information only. Hence, offline signature verification is generally regarded as the more challenging task. The present chapter reviews the field of offline signature verification and presents a comprehensive overview of methods typically employed in the general process of offline signature verification.

Keywords Offline signature verification · Image preprocessing · Handwriting representation · Signature classification

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1 Introduction

For several hundred years, *handwritten signatures* have been used as biometric authentication and verification measure in a broad range of business and legal transactions around the world. In fact, the first use of handwritten signatures can be traced back to the fourth century, where a signature was used to protect the *Talmud* (i.e. a central text in *Rabbinic Judaism*) against possible modifications. Later on, signatures (i.e. so-called *subscripto*) were used to authenticate documents in the Roman Empire during the period of Valentinian III [14]. More recently, several national and international digitization efforts for electronic signatures have been proposed. Yet, handwritten signatures remain very popular [8, 19, 20]. This is mostly due to the ubiquitous applicability as well as the overall high availability and acceptance of handwritten signatures when compared with electronic signatures.

Due to the high commercial and legal relevance, handwritten signatures also expose a certain risk of misuse. To mitigate this risk, *signature verification* can be employed. That is, a *questioned* signature is compared with a set of *reference* signatures in order to distinguish between *genuine* and *forged* signatures [20]. Traditionally, this task has been conducted by human experts as part of *graphology*, i.e. the study of handwriting. However, due to increasing number of documents, automatic signature verification systems have been proposed already some decades ago [28]. Actually, manual signature verification has been continuously replaced since then. Today, automatic signature verification is still regarded as a challenging pattern recognition task, and thus, remains a very active research field [8].

In general, automatic signature verification approaches can be divided into *online* (also termed *dynamic*) and *offline* (also termed *static*) approaches [19]. In the case of online signature verification, signatures are acquired by means of an electronic input device, such as a digital pen, a digital tablet, or via input on a touch screen (e.g. smartphone or handheld device). Hence, dynamic temporal information about the signing process (e.g. acceleration, speed, pressure, and pen angle such as altitude and azimuth) can be recorded during the handwriting process. In contrast, offline acquired signatures are digitized by means of scanning. As a result, the verification task is solely based on the (x, y)-positions of the handwriting (i.e. strokes), and thus, offline signature verification is generally considered the more challenging case. Note that the present chapter focuses only on offline signature verification.

Signature verification systems can also be distinguished with respect to the representation formalism that is actually used, viz. *statistical* (i.e. vectorial) and *structural* representations. The vast majority of signature verification approaches make use of statistical representations [8, 19]. That is, feature vectors or sequences of feature vectors are extracted from handwritten signature images. In early approaches, features are, for example, based on global handwriting characteristics like contour [6, 16], outline [10], projection profiles [30], or slant direction [2, 13]. However, more generic and local feature descriptors (i.e. descriptors that are not limited to handwriting images) were also used such as *Histogram of Oriented Gradients (HoG)* [41] and *Local Binary Patterns (LBP)* [12, 41]. In recent years, features have increasingly been extracted by means of a learned statistical model, viz. *Deep Learning* approaches like *Convolutional Neural Networks (CNNs)* [7, 18, 26]. Regardless of the actual type of feature, different statistical classifiers and/or matching schemes have been employed to distinguish genuine from forged signatures. Known approaches are for example *Support Vector Machines (SVMs)* [10, 12, 41], *Dynamic Time Warping (DTW)* [6, 30], and *Hidden Markov Models (HMMs)* [10, 13].

In contrast to statistical representation formalisms, structural (i.e. string-, tree-, or graph-based) approaches allow representing the inherent topological characteristics of a handwritten signature in a very natural and comprehensive way [27, 33]. Early structural approaches are, for example, based on the representation of stroke primitives [33], as well as critical contour points [4]. In a recent paper, graphs are used to represent characteristic points (so-called *keypoints*) as well as their structural relationships [27]. Hence, both the structure and the size of the graph is directly adapted to the size and complexity of the underlying signature. Moreover, these graphs are able to represent relationships that might exist between substructures of the handwriting.

However, the power and flexibility of graphs is accompanied by a general increase of the computational complexity of many mathematical procedures. The computation of a similarity or dissimilarity of graphs, for instance, is of much higher complexity than computing a vector (dis)similarity. In order to address this challenge, a number of fast matching algorithms have been proposed in the last decade that allow comparing also larger graphs and/or larger amounts of graphs within reasonable time (e.g. [15, 32]).

The goal of the present chapter is twofold. First, the chapter aims to provide a comprehensive literature review of traditional and recent research methods in the field of offline signature verification. Second, the chapter provides a profound analysis of the end-to-end process of signature verification. In particular, the chapter discusses the problems and solutions of data acquisition, preprocessing, feature extraction, and signature classification. Hence, this chapter serves as a literature survey as well as a possible starting point for researchers to build their own process pipe for signature verification.

The remainder of this chapter is organized as follows. Section 2 presents a generic signature verification process. Subsequently, the most important processing steps are individually reviewed in the following sections. First, different publicly available offline signature datasets are compared in Sect. 2.1, while common image preprocessing methods are examined in Sect. 2.2. Next, Sect. 2.3 compares different statistical and structural representations that are eventually used for classification (reviewed in Sect. 2.4). Finally, Sect. 3 presents conclusions and possible trends in the field of signature verification.

2 Signature Verification Process

Most signature verification systems are based on four subsequent processing steps, as shown in Fig. 1 [8, 20]. First, handwritten signatures are digitized by means of scanning (in Sect. 2.1 this particular step is discussed in detail). In the second step, signatures are segmented and preprocessed to reduce variations (discussed and reviewed in Sect. 2.2). Next, preprocessed signature images are used to extract statistical (i.e. vectorial) or structural (i.e. string, tree, or graph) representations (discussed and reviewed in Sect. 2.3). Finally, a questioned signature q of claimed user u is compared with all reference signatures $r \in R_u$ by means of a specific dissimilarity measure (discussed and reviewed in Sect. 2.4).

Roughly speaking, if the minimal dissimilarity to all references is below a certain threshold, the unseen signature q is regarded as genuine, otherwise q is regarded as forged. In general, the larger the reference set R, the better the accuracy of the verification process. However, the acquisition of arbitrarily large reference sets is often not possible in practice, and thus, limited to a few reference signatures per user. In the following sections, each process step is reviewed separately.

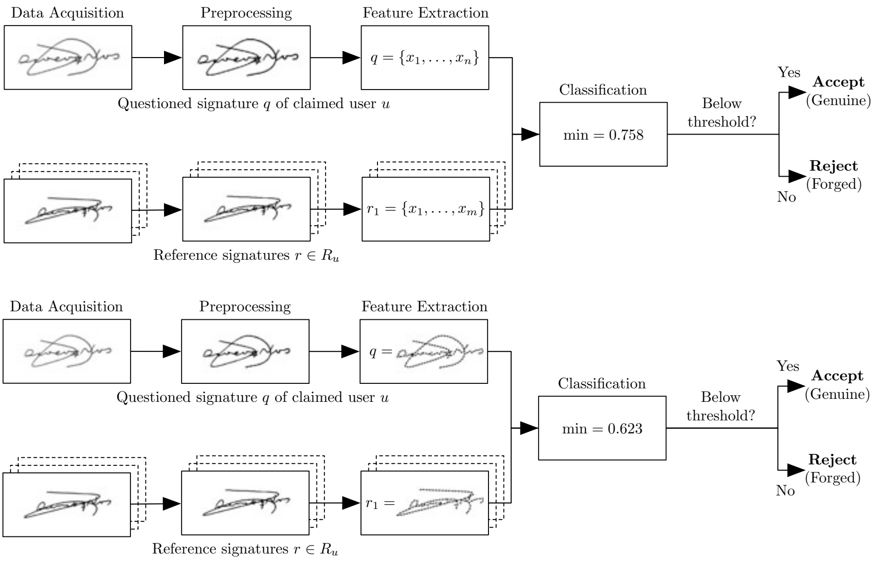


Fig. 1 Statistical (**a**) and structural (**b**) signature verification processes consist of four major steps: First, handwritten signatures are digitized by means of scanning. Second, noise and variations are reduced by means of different preprocessing algorithms. Next, preprocessed and filtered signature images are represented by either a statistical or a structural representation. In either case, a questioned signature q of claimed user u is compared with the corresponding set of reference signatures $r \in R_u$ of user u. If the minimal dissimilarity between q and $r \in R_u$ is below a certain threshold, q is regarded as genuine, otherwise q is regarded as forged

2.1 Data Acquisition and Available Datasets

During data acquisition, the available signature images are digitized into a machine-processable format by means of scanning. In most cases, digitized signatures are based on greyscale images, commonly defined as [37]

$$\{S(x, y)\}_{0 \le x \le X, 0 \le y \le Y},$$

where $S(x, y)$ denotes the greyscale level at the (x, y)-position of the image and X, Y refer to the maximum values of the x- and y-axis of the image. Typically $S(x, y)$ lies between 0 (= black) and 255 (= white).

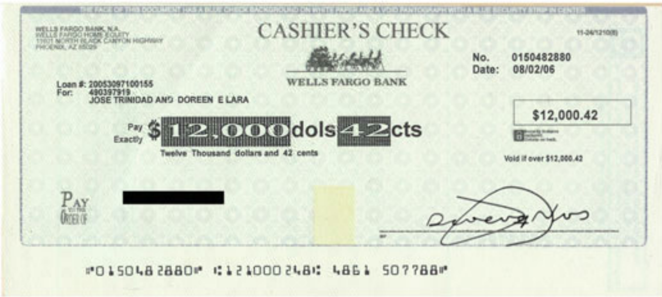
In the last decades, a number of different private and public datasets for offline signature has been proposed, see [8] for an exhaustive overview. These datasets can be characterized with respect to their writing style (e.g. Arabic, Bengali, Chinese, Persian, Western, etc.) as well as the number of genuine and forged signatures per user. Table 1 summarizes four widely used and publicly available datasets. In particular, the table shows summaries of three datasets with real world signatures (i.e. MCYT-75 [13, 29], UTSig [34], and CEDAR [21]) as well as one synthetic dataset (i.e. GPDSsynthetic-offline [11]) for two different writing styles (i.e. Western and Persian). Note that GPDSsynthetic is replacing the widely used GPDS-960 dataset [40] that is no longer available due to new data protection regulations.

2.2 Preprocessing of Signature Images

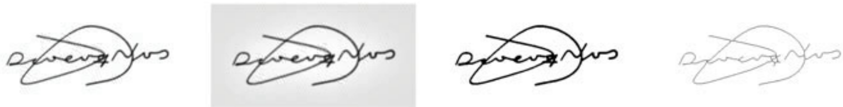
Once handwritten signatures are digitally available, preprocessing basically aims to reduce variations caused by the image itself (e.g. noisy background, skew scanning, segmentation from the background) as well as variations caused by inter- and intrapersonal variations in the handwriting (e.g. scaling and slant of handwriting). In most cases, preprocessing is based on several subsequent steps. First, signatures are extracted from the background (e.g. bank checks). Next, a certain filtering and binarization is employed before different normalization techniques are typically applied.

Table 1 The writing style, the number of users, the number of genuine and forged signatures per user, and the resolution of the images in dpi of widely used datasets for offline signature verification

Name	Style	Users	Genuine	Forgeries	dpi
MCYT-75	Western	75	15	15	600
GPDSsynthetic-offline	Western	4000	24	30	600
UTSig	Persian	115	27	42	600
CEDAR	Western	55	24	25	300



(a) Original



(b) Segmentation (c) Filtering (d) Binarization (e) Skeletonization

Fig. 2 Common image preprocessing steps for GPDSsynthetic-Offline [11]: **a** bank check with signature,[4] **b** segmented signature image, **c** filtering by means of Difference of Gaussian, **d** binarization by means of thresholding, **e** skeletonization by means of morphological operators

Note, however, that the process sequence is not given *a priori*. The following paragraphs give an overview of some common methods and techniques that are widely accepted as standard preprocessing steps. These steps can be divided into four main phases (see also Fig. 2):

1. Segmentation
2. Filtering
3. Binarization
4. Skeletonization

For an exhaustive overview on preprocessing techniques, see [8, 20].

1. Segmentation

As illustrated in Fig. 2a, the signatures are in many cases part of some larger document (e.g. bank checks or forms), and thus, need to be extracted first. Especially bank checks are regarded as a challenging segmentation problem due to colored background images, logos and preprinted lines. To address this issue, different segmentation approaches have been proposed in the literature [2, 12, 13, 33]. In [9], for example, the segmentation is based on subtracting a blank check from the signed artifact. More generic approaches, are based on *Speeded Up Robust Features (SURF)* features in combination with an Euclidean distance metric [1]. Recently, different Deep Learning techniques based on CNNs have been proposed for this task [22, 34]. In general, the importance of signature segmentation is decreasing due to two reasons: First, the increasing use of blank signature fields and second, the declining importance of bank checks.