Evolution of Enterprise Architecture for Intelligent Digital Systems

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Abstract. Intelligent systems and services are the strategic targets of many current digitalization efforts and part of massive digital transformations based on digital technologies with artificial intelligence. Digital platform architectures and ecosystems provide an essential base for intelligent digital systems. The paper raises an important question: Which development paths are induced by current innovations in the field of artificial intelligence and digitalization for enterprise architectures? Digitalization disrupts existing enterprises, technologies, and economies and promotes the architecture of cognitive and open intelligent environments. This has a strong impact on new opportunities for value creation and the development of intelligent digital systems and services. Digital technologies such as artificial intelligence, the Internet of Things, service computing, cloud computing, blockchains, big data with analysis, mobile systems, and social business network systems are essential drivers of digitalization. We investigate the development of intelligent digital systems supported by a suitable digital enterprise architecture. We present methodological advances and an evolutionary path for architectures with an integral service and value perspective to enable intelligent systems and services that effectively combine digital strategies and digital architectures with artificial intelligence.

Keywords: Digitalization and digital transformation · Intelligent digital systems · Digital enterprise architecture · Architecture and systems evolution

1 Introduction

Influenced by the transition to digitalization, many companies are in the process of converting their strategy, culture, processes and information systems to digitalization and artificial intelligence. Today, the digital transformation [1] profoundly disrupts existing companies and economies. The potential of the Internet and related digital technologies such as the Internet of Things, cognition and artificial intelligence, data analysis, service computing, cloud computing, blockchain, mobile systems, collaboration networks, cyber-physical systems, and Industry 4.0 are strategic drivers and enable digital platforms with rapidly evolving ecosystems of intelligent systems and services based on service-dominant logic [2].

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Digitalization [3] promotes the development of IT systems with many, globally available and diverse, rather small and distributed structures, such as the Internet of Things or mobile systems, which have a strong influence on the architecture of intelligent digital systems and services. Data, information, and knowledge are fundamental concepts of daily activities and drive the digital transformation [4] of today's global society. New services and intelligent, connected digital systems extend physical components by providing additional information and connectivity services using the Internet. Intelligent digital systems are information systems that use artificial intelligence (AI) [5, 6] to support and relieve people, and that interact with people. Advances in artificial intelligence have led to a growing number of intelligent systems and services.

The current work in progress paper focuses on the main research question: *What are key drivers and conceptual models of an advanced digital enterprise architecture that supports intelligent digital systems and services?*

We will proceed as follows. First, we establish the architectural context for digitalization and digital transformation to intelligent digital systems. Then we will introduce basic mechanisms of artificial intelligence and provide insights into our current work on a platform for intelligent digital systems. We present our view of a suitable multi-perspective digital enterprise architecture. We outline fundamental aspects of an architectural evolution path for intelligent digital systems. Finally, in the last section, we conclude our research results and mention our future work.

2 Digitalization and Digital Transformation

In the beginning, digitization was considered a primarily technical term [1]. Therefore, a number of technologies are often associated with digitalization [3]: cloud computing, big data combined with advanced analytics, social software, and the Intranet of Things. New technologies, such as deep learning, are strategic enablers and strongly linked to the progress of digitalization. They enable the use of computers for activities that were previously considered exclusively for humans. Therefore, the current emphasis on intelligent digitalization is becoming an essential research area. Digital services and related products are software-intensive and, therefore, malleable and usually service-oriented [7]. Digital products are able to enhance their capabilities by accessing cloud services and to change their current behavior.

We are at a turning point in the development and application of intelligent digital systems. We see great prospects for digital systems with artificial intelligence (AI) [5, 6], with the potential to contribute to improvements in many areas of work and society through digital technologies. We understand digitization based on new methods and technologies of artificial intelligence as a complex integration of digital services, products, and related systems. For years we have been experiencing a hype about digitalization, in which the terms digitization, digitalization, and digital transformation are often used in a confusing way. The origin of the term digitalization is the concept of digitization. According to [8], Fig. 1, we distinguish levels of digitalization.

When we use the term digitalization, we mean more than just digital technologies. Digitalization [1, 8] bundles the more mature phase of a digital transformation from analog over digital to fully digital. Through digital substitution (digitization), initially, only analog media are replaced by digital media, taking into account the same existing business values, while augmentation enriches related transformed analog media functionally. In a further step of the digital transformation, new activity patterns or processes are made possible by a digitally supported modification of the basic concepts.

Digitalization Level	Description	Transformation Type	Example
1. Substitution	Tool substitute, no functional change	Digital Enhancement (1)	Scientific paper as pdf file
2. Augmentation	Tool substitute, functional improvements	Digital Enhancement (2)	Enhanced pdf file with direct connectors to processes / tools
3. Modification	Significant operation redesign	Digital Transformation (1)	Paper submission automatically triggers the subsequent review process
4. Redefinition	Creation of new operations, previously inconceivable	Digital Transformation (2)	Digital platform and ecosystem of living scientific conferences, journals, and other assets with co-creating people and intelligent services

Fig. 1. Digitalization and digital transformation.

Finally, the digital redefinition (digitalization) of processes, services, and systems results in completely new forms of value propositions [1, 2] for changing businesses, services, products, processes, and systems. Digitalization is thus more about shifting processes to attractive, highly automated digital business processes and not just about communication via the Internet. The digital redefinition usually leads to disruptive effects on business. Beyond the value-oriented perspective of digitalization, intelligent digital business requires a careful adoption of human, ethical, and social principles.

3 Intelligent Digital Systems

The combination of hardware and software product components with intelligent services from the cloud enables new ways of intelligent interaction with customers, as described in [9]. The life cycle of digitized products is extended by intelligent services. One example is Amazon Alexa, which combines a physical device with a microphone and loudspeaker with services, the so-called Alexa skills. Users can extend the capabilities of Alexa with capabilities similar to apps. The set of Alexa capabilities is dynamic and can be adapted to the customer's requirements during runtime. Alexa enables voice interaction, music playback, to-do lists, setting alarms, streaming podcasts, playing audio books, and providing weather, traffic, sports, and other real-time information such as news. Alexa can also connect and control intelligent products and devices.

From today's perspective, probably no digital technology is more exciting than artificial intelligence, which offers massive automation possibilities for intelligent digital systems and services. Most companies expect to gain a competitive advantage from AI.

Artificial intelligence (AI) [5, 6] is often used in conjunction with other digital technologies [10] such as cloud computing, analytics, ubiquitous data, the Internet of Things, and unlimited connectivity. Basic capabilities of AI concern automatically generated solutions from previous useful cases and solution elements derived by causal inference structures such as rules and ontologies, as well as learned solutions based on data analytics with machine learning and deep learning with neural networks.

Artificial intelligence receives a high degree of attention due to recent progress [11] in several areas, such as image detection, translation, and decision support. It enables interesting new business applications such as predictive maintenance, logistics optimization, and automatically added customer service management. Artificial intelligence supports decision-making in many business areas. Today's advances in the field of artificial intelligence [10–12] have led to a rapidly growing number of intelligent services and applications. The development of competencies via intelligent digital systems promises great value for science, economy, and society. It is driven by data, calculations, advances in algorithms for machine learning, perception and cognition, planning, decision support, and natural language processing.

The symbolic AI [5], which predominated until the 1990s, uses a deductive, expert-based approach. By interviewing one or more experts, knowledge is collected in the form of rules and other explicit representations of knowledge, such as horn clauses. These rules are applied to facts that describe the problem to be solved. The solution of a problem is found by successively applying one or more rules using the mechanisms of an inference engine [5]. An inference path can usually be followed backwards and offers transparency and rationality over instantiated inference processes by "how" and "why" explanations. The symbolic AI proved to be very effective for highly formalized problem spaces like dedicated expert systems. After the last wave of enthusiasm in the late 1980s, the focus of research shifted to other areas [10–12]. Ontologies [5] represent the second wave of semantic technologies to support knowledge representations.

Unlike symbolic AI, machine learning [10] uses an inductive approach based on a large amount of analyzed data. We distinguish three basic approaches to machine learning: supervised, unsupervised, and reinforcement learning [12]. In supervised approaches to machine learning, the target value is part of the training data and is based on sample inputs. Typically, unsupervised learning is used to discover new hidden patterns within the analyzed data. Reinforcement Learning (RL) is an area of machine learning where software agents work to cooperatively maximize cumulative rewards. The exploration environment is specified in terms of a Markov decision process, as many reinforcement learning algorithms use dynamic programming techniques. Reinforcement learning does not require marked input/output pairs, and suboptimal actions do not need to be explicitly corrected.

Digital technologies are changing the way we communicate and collaborate with customers and other stakeholders, even competitors, to create value [1, 2]. Digital technologies have changed the way we look at how to analyze and understand a wide range of real-time data from different perspectives. The digital transformation has also changed our understanding of how to innovate in global processes, to archive and develop intelligent digital products and services faster than ever before, to achieve the best available digital technology and quality. We are currently researching a cognitive co-creation platform that enhances key intelligent digital systems. We consider the evolutionary dynamics of an integrated architecture lifecycle management for intelligent artifacts, such as digital strategy, digital operating model, intelligent models for service composition, digital enterprise architecture, and intelligent services and products.

4 Digital Enterprise Architecture

A targeted digital business architecture [1, 3], should be part of an enterprise architecture [13] that provides a comprehensive view of integrated business and IT elements. More specifically, we integrate configurations of stakeholders (roles, responsibilities, structures, knowledge, skills), business and technical processes (workflows, procedures, programs), and technology (infrastructure, platforms, applications) to implement digital strategies and compose value-producing digital products and services. The digital business design does not only include simple business restructuring or just a focus on IT architecture. Above all, digital business is an aspect that is currently in use and constantly changing. Therefore, the digital business design is not an end state.

We start by revisiting and modeling the digital strategy [14], as shown in Fig. 2, which sets the digital modeling direction and establishes the basis and value framework for the business definition models, with the business model canvas [15] and the value proposition canvas [16]. With the basic models for a value-based business [2], we assign these basic digital business models [15, 16] to a business operating model [1]. The value perspective of the business model canvas [15] leads to appropriate mappings to the value models of the enterprise architecture supported by ArchiMate [17, 18]. Finally, we set the framework for the systematic definition of digital services and associated products by modelling digital services and product compositions.

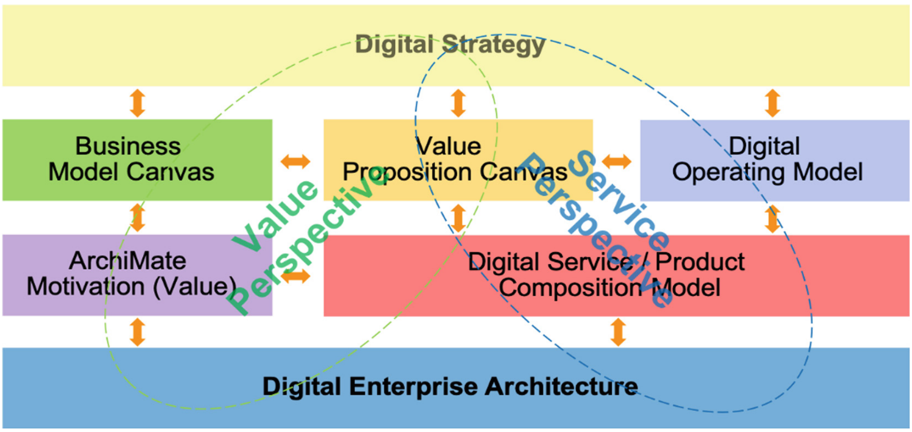

Fig. 2. Integral value and service perspective.

We have extended our service-oriented enterprise architecture reference model [19] for the evolving context of digital transformation by microgranular structures and the consideration of related multi-perspective architectural decision models, supported by viewpoints and functions of an architecture management cockpit. DEA - Digital Enterprise Architecture Reference Cube provides a holistic architectural reference model for the bottom-up integration of dynamically composed micrgranular architectural services [7, 20], and their models (Fig. 3).

Enterprise Architecture Management [13], as defined today by various standards such as [18], uses a fairly large number of different views and perspectives to manage current IT. An effective and agile architecture management approach for digital enterprises should also support the intelligent digitalization of products and services and be both holistic and easily adaptable [19]. A successful digital architecture should use a service platform [3] that supports a network of actors-to-actors and hosts a set of loosely coupled services as part of a rapidly growing digital ecosystem [2, 3]. A service platform is a modular structure that connects and integrates resources and actors sharing institutional logics [19] and promotes the value co-creation [1] through the exchange of services according to the service-dominant logic [2].

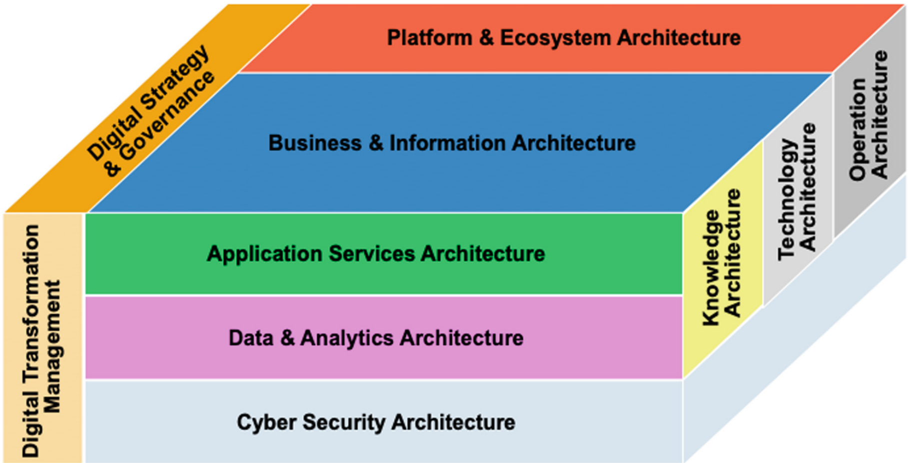

Fig. 3. Digital enterprise architecture reference cube.

The traditional operational backbone of core IT services [1] does not provide the transition speed and flexibility required for continuous, rapid, and agile digital innovation because it is designed for stability, reliability, and efficiency. As a result, digital enterprises are designing a second backbone for the use and hosting of digital services. The digital services backbone [14] brings together business and technology competencies that enable rapid development and deployment of digital innovation. The backbone of digital services includes: digital components as a set of business and technical services; platform as service: a technology environment that hosts large amounts of loosely coupled software as a service, such as microservices; repositories for the continuous collection of large amounts of human and sensor data; analytics to transform data insights into meaningful recommendations and links to data, systems, and processes from the operational backbone.

The ability of a platform to grow rapidly is based on the principle of network effects [1] and smooth entry points for a large number of new participants. Mature platforms often evolve towards greater openness. The value of platforms is derived from the community they serve. The design of a platform should first support its core interaction, which is easily accessible and inevitable. Therefore, a digital platform [2] should provide three core functions: Pull, facilitation, and matching. As the participants and resource base of the platform grows, participants will find new ways to interact to expand the core interaction. Digital platforms are superior to traditional fixed value chains because of the value generated by network effects, which often enable essential disruptive changes in business operations.

5 Evolution Path

Intelligent or smart service systems [21] bring together people, technology, organization, and information. Intelligent or cognitive digital systems [10] are instrumented by sensors and actors [20], store data in the cloud and are accessible from multiple devices. These systems are able to learn, adapt dynamically, and make decisions. Therefore, the design of intelligent service systems requires a clear understanding of human interaction with technology and a human-centric design [21].

Decision analytics offers increasingly complex support, especially in the development and evolution of sustainable digital architectures [19]. We can identify two far-reaching perspectives of software evolution: First, software can be designed to anticipate changes by the original software developer to facilitate evolution by predicting possible change perspectives of new software. The main mechanism of proactive change is based on the modularity of service structures. Secondly, software evolution can be managed during the maintenance phase by using specific tools and methods.

An important prerequisite for building and analyzing solid digital service systems and enterprise architectures [13, 19] is a formal understanding of the nature of services [7] and their model-based relationships. We currently have to consider a major shift from the traditional software engineering approaches of the closed world to open service systems with autonomous parts [20].

The main challenges of service computing for the next ten years lead to a redefinition of service computing, as postulated by [22]. The Service Computing Manifesto sets out a strategy that positions new concepts and technologies to support the service paradigm. The Service Computing Manifesto shows the development path of four main artifacts: Data, Information, Knowledge, and Service. The Service Computing Manifesto recommends focusing on four main research directions by specifying both challenges and a research roadmap: Service Design, Service Composition, Crowdsourcing Based Reputation, and the Internet of Things.

6 Conclusion and Future Research

Starting from our basic research question, we first set the context from digitalization and digital transformation to a systematic value-based digital service design according to the service-dominant logic. We identified suitable AI mechanisms to enable intelligent digital systems and services. To support the dynamics of digital transformation with intelligent digital systems, we have developed an adaptive architecture approach for digital enterprise architecture and a deeper understanding of an evolutionary path for both intelligent digital systems and their architecture. The strengths of our research result from our integral approach of an essential model mapping of digital strategies to value-based digital operating models for intelligent digital systems and services on a closely related digital platform, supported by a unified digital architecture reference model. The limitations of our work result from an ongoing validation of our research and open questions in the investigation of extended AI approaches and the management of inconsistencies and semantic dependencies. We are working on a platform to extend human-controlled dashboard-based architectural decision making with AI support.

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